Zeroing In

Some thoughts on making our tank guns More accurate, more effective, and more lethal

by Major Bruce J. Held

Today's Army exists in an era in which threats against our national security interests continue and are becoming increasingly varied, while, at the same time, the Army's budget is being greatly reduced. In such times, increasing the effectiveness of current systems through doctrinal and procedural change can become the best, and sometimes the only, means of maintaining superiority on the battlefield. To make this happen, material and combat developers must work closely together. The approaches they choose to solve new battlefield challenges must creatively combine limited materiel improvements with changes in the way current systems are employed. This article explores one method of improving the lethal effectiveness of our current tanks through policy change. In particular, I will discuss options to current calibration procedures that may make our tanks more accurate, and hence, more effective.

Tank System Lethality

One measure of the lethal effectiveness of a tank system is single shot kill probability, or $P_{k/s}$. This measure, also referred to as the probability of kill given a shot is defined as the probability that a specific tank type, armed with a specific ammunition type, will kill a specific target. For example, given an M1A1, firing an M829 APFSDS-T against the frontal arc of a T-62, the probability that the T-62 will be destroyed with one shot can be estimated.

$P_{k/s}$ is primarily a function of ammunition lethality and tank/ammunition accuracy. Ammunition lethality is defined by a measure called the probability of kill given a hit, or $P_{k/h}$. $P_{k/h}$ is the probability that a given round of ammunition will defeat a target if it hits that target. Figure 1 plots the $P_{k/h}$ for two ammunition types, A and B, against the frontal portion of a specific target. Target penetration depends on the velocity at which the round impacts the target. Since aerodynamic drag slows a round down as it flies, an ammunition's lethality degrades with range and this degradation is reflected in the plot. In this hypothetical case, type A is a later development than type B. It was specifically designed to provide greater lethality than type B and as the chart shows, its $P_{k/h}$ is about 10% better than type B against the target at all ranges.

If I could predict the precise behavior of the fire control system, cannon and ammunition, I would always hit my target. Unfortunately, variations in the behavior of each make exact prediction impossible. Tank/ammunition accuracy error is thus the resultant effect of all the sources of variation involved in firing a tank cannon. In general, accuracy is discussed in two ways. Often, it is described as a tank's total system error, i.e. the combined effect of all the sources of variation. This error is usually measured in mils, so is range independent. A more understandable way of discussing accuracy is in terms of probability of hit, or P_h. Probability of hit is the percentage of rounds fired from a tank that will hit a given target at some range. For unguided ammunition, like tank rounds, P_h decreases with range. Consider a modern tank firing ammunition types A and B. To simplify discussion for this article, the total system error of my tank firing both ammunition types is 0.5 mils in azimuth and elevation. This is roughly equivalent to the capability of a modern tank. Given the system error, the P_h for these rounds can be calculated against a defined target. For my example, I have chosen a target that is tank size. It is 2.2 meters tall and 3.3 meters wide. Figure 2 plots the P_h of types A and B against this target as a function of range. The obvious point of the figure is that the P_h decreases quickly at ranges beyond 1000 meters.

Finally, in Figure 3, I have plotted the $P_{k/s}$ for these two types of ammunition against the target. $P_{k/s}$ is simply obtained by multiplying P_h and $P_{k/h}$ together at each range. Though all of the values presented here are notional and the target is undefined, the plots are reasonable representations of what modern tanks and ammunition can accomplish. There are two points that should be clear from Figure 3. First, the effectiveness of both rounds decreases quickly with range. Additionally, despite type A's greater penetration capability, its overall effectiveness at long range is about the same as type B.

At short range, the probability of hit is nearly 100%, so the ammunition's lethality drives the value of $P_{k/s}$. This is reflected in the greater effectiveness of type A at shorter ranges. At longer ranges, the probability of hit is so low that the difference in lethality becomes masked. At these ranges, system accuracy becomes the dominant parameter for $P_{k/s}$ and the overall effectiveness of the rounds merges at very long range. I should re-emphasize that I have provided a case where the accuracy of the two rounds is the same. This is not normally true.

Typically, design trade-offs affect ammunition accuracy, so that different ammunition types do not have exactly the same accuracy as I have shown. Unfortunately, the trade-off is often between factors that provide greater accuracy and those that provide greater lethality. As an example, consider the length of a penetrator. All else being equal, the longer the penetrator, the greater the penetration capability of the round. Lengthening penetrators, however, can make launching them more prone to variability that adversely affects accuracy. For the example presented here, degrading the accuracy of type A by just 10% causes type A to lose its performance edge over type B at ranges of 1500 meters and beyond, despite its better penetration capability.

My purpose in going through all of the above analysis is to point out that accuracy is a key ingredient of tank effectiveness. We have made great strides in the penetration capability of our rounds, but it is possible to lose that advantage without concurrent improvements in accuracy. Efforts to improve the effectiveness of our tanks must, therefore, include efforts to improve accuracy. Also, to remain relevant in Force XXI, where long range battles will predominate, the Abrams series tank must be given a greater effective lethal range.

Accuracy

Tank system accuracy is a complex subject and there are a large number of error sources that contribute to overall system error. The major contributors to system error, though, are limited to three: round-to-round dispersion[1], occasion-to-occasion dispersion, and tank-to-tank variation.[2] The magnitude of these three error sources varies depending on the ammunition type. Round-to-round dispersion is the inability of a tank to shoot each round through the exact same spot when firing on a particular occasion. This is apparent to any tanker who has fired more than one round during screening exercises. If, within several minutes, a crew fires three rounds at the same aimpoint, without moving the tank, there will be some pattern of shots, not a single hole in the target. Occasion-to-occasion dispersion is the difference between the average hitting point of a tank from one firing occasion to another. These differences occur because small disturbances to the tank or ammunition occur between firing occasions that can affect how the tank shoots. Firing occasions are defined a number of ways. Separate firing occasions may be defined by time, ammunition temperature, movement of the tank, or maintenance on the cannon or fire control systems. Finally, tank-to-tank variation is the error that occurs because, on average, each tank shoots a little bit differently than all other tanks. Since we do not individually zero our tanks, but instead use a common zero, the computer correction factor (CCF), the shooting differences between tanks is a source of error.

Round-to-round dispersion and occasion-to-occasion dispersion are error sources that are primarily technical in nature. What I mean by this is that correcting these error sources requires, primarily, a technical approach; i.e., design changes to the ammunition, tank system or both. Tank-to-tank variation is an error source whose reduction can be accomplished technically, i.e, by tank/ammunition system design and production changes, and/or through policy changes. In the long run, the ideal solution is to produce each tank so they all shoot the same. However, this will be expensive and will require years of investment. As I mentioned above, tank-to-tank errors are related to our current tank calibration policy, the fleet CCF. This suggests that significant gains in the accuracy of our tanks can be accomplished by optimizing the method used to calibrate our tanks. Therefore, I will use the remainder of this article to discuss our current calibration policy and some options to replace it.

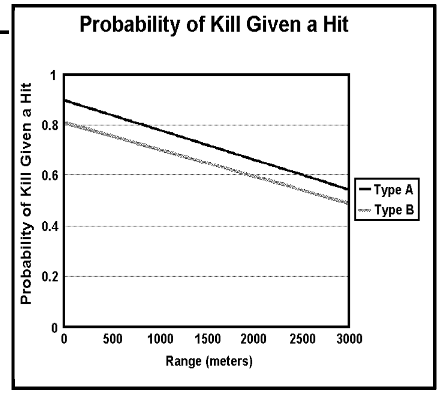

Figure 1

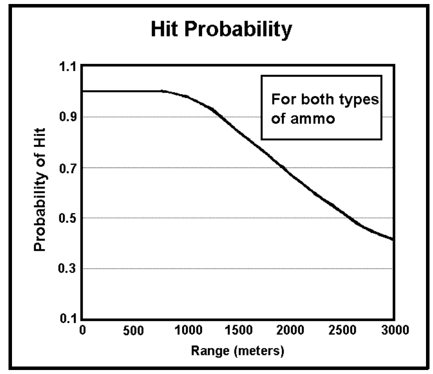

Figure 2

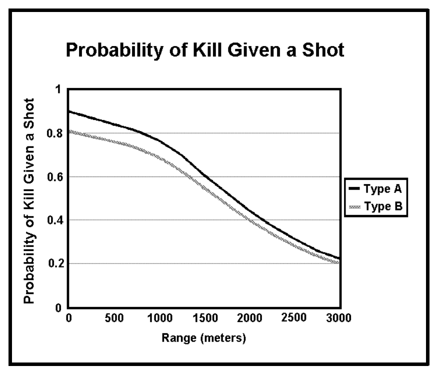

Figure 3

TANK CALIBRATION OPTIONS

Fleet Zero

The U.S. Army has adopted a calibration policy known as the fleet zero for cost, safety and environmental considerations. This policy works well when tank-to-tank variation is small relative to other sources of error. It is implemented by estimating an average ammunition correction factor across the fleet of tanks. This average correction (one for each type of ammunition) is published in the gunnery manuals as the CCF. Every tank then uses the same CCFs.

For training ammunition, M865 and M831, the fleet zero policy has worked well. This is because tank-to-tank variability is relatively small for these ammunition types. There are still some tanks, though, that shoot much differently than most of the others. We recognize this, and as part of each gunnery, test the fleet CCF for each tank through a screening exercise. When screening demonstrates that the fleet CCF does not work for a particular tank (after correcting for maintenance and boresighting problems) that tank is zeroed — provided a new, discreet CCF — and continues through its tank tables.[3]

For service ammunition, screening each tank prior to combat may not always be possible. In this case, the published CCF must be used. This policy has proven effective because the errors associated with the fleet zero policy, though significant, have not been large enough, at typical engagement ranges, to degrade hitting probability to unacceptable levels. In the future, as we demand greater engagement range from our tank systems, and as we expect a greater number of first round hits at current engagement ranges, tank-to-tank errors associated with the fleet zero policy may become unacceptable. Additionally, to gain extra lethality from our new ammunition, we have been pushing the physical and technological limits of the ammunition and the M256 120-mm cannon. There is some evidence to indicate that this may exacerbate tank-to-tank variation, making this error source larger than we have seen in the past. As this occurs, we should consider some other means of calibrating our tanks.

Individual Zero

An alternate method for zeroing tanks is the individual zero. Under this option, each tank fires every type of ammunition that would be used in training or combat. The impact location of each type of round is noted and this information is used as the basis for each tank's individual CCF. Individually zeroing each tank is the Armor Force's version of zeroing an M16 rifle prior to qualifying with it. Some countries that use 120-mm cannons on their tanks, to include the Germans, use a one-time individual zero to calibrate their tanks.[4]

There are several problems with individual tank zero. First is the expense. Modern service ammunition is costly.[5] Since it would take four rounds, and possibly more, of each ammunition type to individually zero a tank only once, the cost of ammunition could be high over the fleet of tanks. If individually zeroing tanks must be done on a repetitive basis, the costs are even higher. Safety is another concern. Individually zeroing the M830 or M830A1, for example, would require special ranges with explosive capability and special handling of the ammunition. Finally there are environmental concerns. Modern KE ammunition uses depleted uranium or tungsten for their penetrators. These materials are heavy metals and therefore pose potential health and environmental hazards. In addition to the logistical problems, individually zeroing each tank does not provide a perfect zero.

Earlier, I talked about occasion-to-occasion dispersion. A tank will fire somewhat differently on different firing occasions. Therefore, zeroing a tank on one occasion does not necessarily mean it is well zeroed for another occasion. The real question then becomes whether the occasion-to-occasion dispersion is larger than the tank-to-tank variation. If it is, individually zeroing each tank could actually make accuracy worse if the tank is zeroed on a different occasion than the training or combat event. On the other hand, if the tank-to-tank variation is the larger error, individually zeroing the tank will improve accuracy, compared to a fleet zero.[6]

If there is an occasion-to-occasion problem, there are several possible methods to get around it. First is to zero as a part of every combat or training occasion. Unfortunately, this will not always be possible in combat situations, and it would prove expensive and logistically burdensome. Another option is to zero the tank over many occasions, when conditions permit. By maintaining a history of where a tank shoots, the average zero location for that tank can be established. The average could then be used as the zero for the tank. Again, many rounds of each type are required for this strategy and the cost could be prohibitive. Finally, as the conditions that cause occasion-to-occasion dispersion are better understood, control of those conditions on zeroing occasions could significantly reduce their impact on occasion-to-occasion dispersion, thus making individual zero a more viable option.[7]

The 'tube zero' is a variation on the individual zero. Each cannon has its own unique centerline profile. The assumption behind the tube zero concept is that a cannon's centerline profile makes the strongest contribution to its unique firing characteristics. There is some evidence that suggests this may be the case.[8] Under a tube zero concept, each gun tube would be sent to a proving ground after manufacture and all ammunition types would be fired from each gun tube. The zero values for the various ammunition types would then be sent with the gun tube and would be available when it is installed in a tank. This concept still requires a good deal of ammunition, though the safety and environmental concerns are eased by firing at a proving ground. More importantly though, there are thousands of 120-mm gun tubes already installed on tanks or in storage at depots. Getting all of these gun tubes to a proving ground is impractical. Even if that were initially possible, every time a new round of ammunition was introduced, the tube would again have to be sent away for zeroing.

Surrogate Zero

The surrogate zero concept has been around for a number of years.[9] Here, the idea is to individually zero each tank in the fleet with training ammunition or specially developed inert slugs. The zero value obtained for each tank is then used as a surrogate for the zero values that tank would use with the various service rounds. This eliminates the need to zero each tank with ammunition that may be dangerous, expensive, or environmentally hazardous. The ideal surrogate round is therefore inexpensive, safe. and environmentally benign.

The best example of how such a concept might work is with the M830 High Explosive, Anti-Tank (HEAT) round and its complementary training round, the M831. The M831 was designed to behave identically to the M830 in terms of interior and transitional ballistics and its free flight dynamics. Since the M831 lacks the explosive warhead of the M830, however, each tank could safely zero with the

M831 and use those zero values as surrogate individual zero values for the M830.[10]

Currently, other than the M830, no other U.S. service round has a corresponding training round specifically designed to mimic its ballistics. The entire series of Kinetic Energy 120-mm ammunition in the U.S. fleet (M829 through M829A2) uses one type of training round, the M865, and its ballistics differ from all the M829 family of ammunition. The M830A1 Multi-Purpose, Anti-Tank (MPAT) has no training round at all. In these cases, for the surrogate zero concept to work with a training round, a repeatable relationship needs to be established between the zero values for the service ammunition and the training round. This relationship must be statistically significant but does not need to be perfect. It only needs to be good enough to improve the hitting probability across the tank fleet over that achieved with a fleet zero policy.

Recent tests with the M829A2 and the M865PIP have shown some promise in the surrogate zero concept. If the surrogate zero concept proves viable with training rounds, it could be a relatively cheap way of individually zeroing tanks. Since tanks currently screen with training rounds prior to gunnery tables, a procedural change could be instituted to maintain the impact history of M865 and M831 for each tank. For example, if the 2408-4 is modified,[11] this history could easily be maintained with the tank. Battalion master gunners could then use the firing history of the training rounds to calculate each tank's CCFs for the various service rounds.

As with the individual zero, a surrogate zero will only work if the occasion-to-occasion dispersion is smaller than the tank-to-tank variation or if each tank's average shooting tendency is known over many occasions. Maintaining a history of how the tank shoots training rounds and using the average impact point to develop surrogate zeros is a partial answer. Also, as in the case of individual zero, understanding what affects a tank's firing characteristics and accounting for them some way, could improve the precision of a surrogate zero technique.

Silent Zero

The 'silent zero' is another proposed method[12] for individually zeroing tanks. This proposed calibration method eliminates many of the logistical type problems associated with other calibration methods, such as safety, cost and environmental hazards. Additionally, 'silent' zero eliminates many of the potential accuracy errors associated with the other techniques.

The silent zero concept assumes that all the major sources of tank-to-tank variation are well understood. If they are, the error sources may be modelled on a computer and each tank's CCF values could be computationally derived.[13] Under the silent zero concept, all the characteristics of a tank system that make it unique in the way it fires (such as its gun-tube centerline profile) are measured. Knowledge of these parameters allows construction of computer simulations that replicate each tank's unique firing characteristics. The computer then 'fires' each type of ammunition from its model tank and the CCF values are derived. These values can then be maintained with that tank until a system change requires a new simulation. New simulations could be conducted at some central location, such as a depot. Alternatively, if the data about the tank system was maintained in some data base and if the model did not require supercomputer capability, a battalion master gunner could run the simulations on a PC and generate new CCFs at battalion HQs.

The capability to conduct a 'silent zero' is still some time away. There is still a good deal that we do not understand concerning how large cannons behave when they are fired. Additional research is therefore required if this option is to become a possibility. Depending on the parameters that are determined to be needed for the computer simulations, a potentially very large data base would also have to be assembled. The potential benefits, however — ammunition cost savings, improved accuracy across the fleet, and technical spinoffs from the research — make the 'silent zero' an option worthy of consideration.

Conclusion

The U.S. Army will have to rely on the M1A1 and M1A2 tanks for the foreseeable future. In order to maintain their battlefield edge and keep them relevant in Force XXI, continual improvements in lethality at long range are essential. This means that we must make the tank/ammunition system more accurate. One potential method to do this is to alter our current calibration policy.

I have discussed basic strategies for calibrating tanks. Each one of these has its own problems and advantages, so determining the proper zeroing technique for the U.S. Army's tank fleet requires balancing the pros and cons of each one. The Army's current policy, the fleet zero, is economical and was used successfully during DESERT STORM. The other policies, individual zero, surrogate zero and silent zero, are all unproven, but all have the potential to improve long range accuracy if errors associated with their implementation are kept in control. They therefore deserve a strong look. Finally, some hybrid approach, may prove the most useful. We already use a combination of fleet CCF and individual zero for training rounds. Perhaps such an approach could also improve the accuracy of our service ammunition.

The bottom line is that, with little funding for new tanks or upgrades to existing models, we must maximize the capability of our current systems, the M1A1 and M1A2. Improving accuracy is one way to maximize their capability by significantly improving their long range effectiveness. Without a materiel change to the tank however, changing our calibration policy is one of the only methods to significantly improve accuracy. There are a number of potential methods available and they should be pursued aggressively.[14]

Footnotes

[1] Held, B., D. Webb, E. Schmidt, "Identification and Quantification of Sources of Occasion-to-Occasion Elevation Variability in Tank Gun Accuracy," Proceedings of the Seventh U.S. Army Symposium on Gun Dynamics, May 1993, pp. 103-104.

[2] Gunner lay is an error source that I have chosen not to address in this article. Gunner lay error includes effects that can be categorized as round-to-round, occasion-to-occasion, and tank-to-tank. Luckily, though this error source can be large, it is also the one that tankers can control or minimize. The best way to reduce gunner lay errors is through repetitive and correct training. I also assume for this article that boresight retention is controlled by boresighting often and by conducting MRS updates frequently.

[3] A screening policy that identifies tanks that are not accurate with a fleet CCF and individually zeroes them may, in fact, be the most accurate calibration technique.

[4] Minutes of the 22nd JCB Meeting, 120mm Tank Main Armament System, 14-16 May 1991, Munich, Germany.

[5] Training ammunition costs several hundred dollars a round, and service ammunition, par-

ticularly the newer types, costs several thousand dollars a round.

[6]Data to determine the magnitude of occasion-to-occasion error is scanty and somewhat conflicting. Additional testing is needed.

[7]For example, if ammunition temperature is determined to be the greatest root cause of occasion-to-occasion variability, it may be possible to control the temperature of the ammunition used to individually zero a tank.

[8]Schmidt, Edward M., briefing to PM TMAS, 20 December 1994, Picatinny Arsenal, NJ.

[9]I am not sure who originated the surrogate zero concept, but I first heard of it from Dr. Schmidt in 1989.

[10]Use of the M831 as a surrogate for the M830 has not been proven and should not be used in the field until it is. The fact that the M830 and M831 have different fleet CCFs indicates that we cannot assume that a particular tank will fire the two the same.

[11]This idea suggested by SSG(P) Robert Horner of 5th Sqn., 16th Cav., Fort Knox.

[12]Proposed by Dr. Schmidt at 22nd JCB Meeting, Munich, 1991.

[13]Work at the Army Research Laboratory (ARL) attempted a simulated tank firing using three tank systems. The results were promising, but are not yet good enough for a silent zero. [Bornstein, J., D. Savick, D. Lyon, E. Schmidt, J. Kietzman, D. Deaver, "Simulation of Tank Cannon Launch Dynamics," Proceedings of the Seventh U.S. Army Symposium on Gun Dynamics, May 1993, pp. 226-237.] Since this effort, much better computer models of the cannon and projectile dynamics have been constructed by Dr. Steve Wilkerson, et. al. at ARL. [Wilkerson, S., "Analysis of a Balanced Breech System for the M1A1 Main Gun System Using Finite Element Techniques," Technical Report 608, U.S. Army Research Laboratory, Aberdeen Proving Ground Md., November 1994.] These new models should greatly enhance the capability to predict projectile impacts. Finally, LTC Robert Dillon of the U.S. Military Academy has recently had very encouraging results with fairly simple simulations. He has been able to predict projectile impacts to within a half a mil. [Dillon, R., "120-mm Projectile Dynamic Response to Launch Conditions," to be published in the Proceedings for the AIAA Atmospheric Flight Mechanics Conference, August, 1995.]

[14]I would like to thank COL Richard Bregard, Mr. Vincent Rosamilia, and LTC Jim Burton of the Office of the Project Manager for Tank Main Armament Systems for making comments and very helpful suggestions after they read early drafts of this article. I would especially like to thank Mr. Al Pomey of the Armor School at Ft. Knox who also read early drafts of the article and prevented a couple of embarassing errors.

Major Bruce Held earned his commission in 1980 from the United States Military Academy at West Point. He initially served in the 32d Armor as an S2 and scout platoon leader and went on to an assignment in the 2d Armored Cavalry as an S4 and troop commander. As an Acquisition Corps officer, he has served at the Army Research Laboratory and is currently serving in the Office of the Project Manager for Tank Main Armament Systems. In addition to his BS degree from West Point, he holds an MS from Stanford University in Aerospace Engineering and a law degree from the University of Maryland School of Law. He is also a graduate of MIOBC, AOAC, and CGSC.