Every mil matters

One battalion’s fight against error

By Lt. Col. Jim Collins and Capt. Joshua Herzog

Troubleshooting is a complicated task that requires an understanding of ballistics, firing tables and the automated systems. Due to the breadth of knowledge and experience required for proper troubleshooting, it remains a leader-centric task that many are reluctant to embrace. Training Circular 3-09.81 “Field Artillery Gunnery” states “unit leaders or investigating officers need to be able to evaluate firing data and supervise corrective action for inaccuracies.”

While absolutely true, the degree to which leaders evaluate firing data can be generalized into the following categories:

1. **Insufficient troubleshooting.** The practice of theorizing the cause of the error then concluding the solution is beyond the control of the firing unit i.e., inconsistent propellant burns or incorrect metrological data.
2. **Elementary troubleshooting.** Isolating an error using logic but unable to support it with a mathematical solution i.e., muzzle velocity is causing the range error.
3. **Adequate troubleshooting.** Isolating errors using logic then validating the logic with mathematical computation(s).

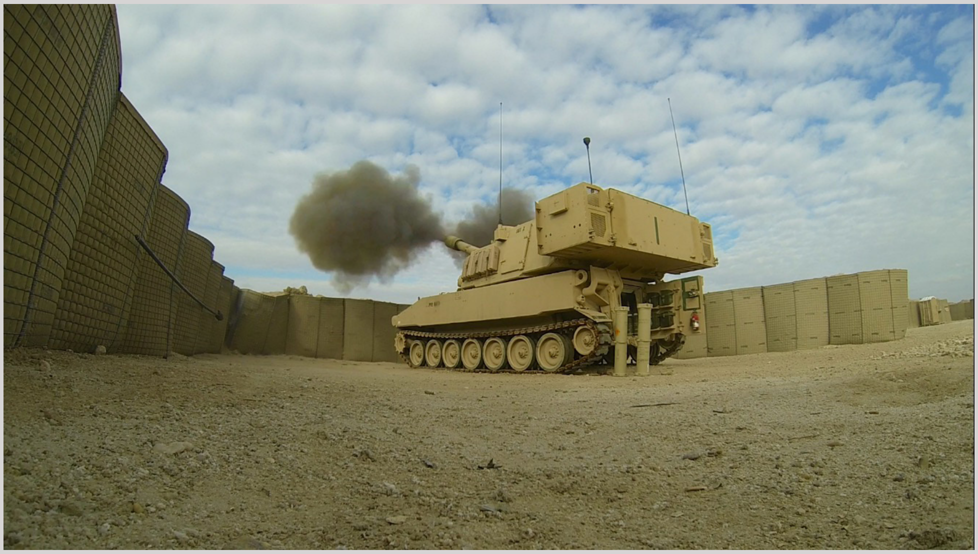
Over the past 18 months, the leaders of 1st Battalion, 7th Field Artillery Regiment have emphasized troubleshooting and gradually impressed a culture of accuracy by analyzing every mission when a round impacts outside of three probable errors in range and/or deflection. “Check-firing” no longer has the context of negligence, but a context of professionalism.

First Battalion, 7th Field Artillery Regiment is currently deployed to Southwest Asia in support of Operation Spartan Shield and Operation Inherent Resolve. The current mission requires a field artillery battalion ready to suppress, neutralize or destroy the enemy in decisive action operations, while simultaneously operating autonomous platoons to assist joint and multinational partners in a complex operational environment. Mission-essential task training that culminated with a rotation at the National Training Center prepared us for the aforementioned mission but the latter is more complex. Not only did it require additional training, it required a renewed culture of exacting standards.

First, through training and education, we had to acknowledge that “good enough” is no longer acceptable and instead we inculcated three principles:

1. The Precision Guided Kit (PGK) and Excalibur give the field artillery an unprecedented degree of precision. However, this does not replace the requirement for accurate high explosive/point detonating. We must resist the tendency to default to PGK/Excalibur because all other munitions are “inaccurate.”
2. In the 1st Infantry Division, training and leader development are synonymous. While we train to deliver rounds on target, we must develop leaders that are capable of understanding the variables that cause inaccuracies, then isolate and perform trouble-shooting procedures.
3. Accuracy is not subjective – in most cases the tabular firing tables define error. For example, at 14,000 meters acceptable error for a M795 projectile with M232A1 Charge 4 is between 27 and 107 meters due to dispersion based on the percentage of rounds that will land within one to four probable errors in range. A round 108 meters off target is unacceptable. The following vignettes describe scenarios where we identified and solved inaccuracies, but more importantly junior leaders received a renewed sense of Redleg professionalism.

Soldiers from 1st Battalion, 7th Field Artillery Regiment, fire an Excalibur round from a Paladin during a live-fire exercise. (Courtesy photo)



Target location error

First, to “simplify” troubleshooting, we attempted to minimize the number of nodal variables that contribute to inaccuracies: fire support, fire direction and cannon operations. We focused on the technical aspects of reducing target location error. Fire support equipment, when used to its full capabilities within the armored brigade combat team’s MTOE (modified table of organization and equipment), minimizes target location error. Understanding system capabilities is critical to understanding the degree of accuracy that can be achieved, and in turn, reduce the compounded error. After a deliberate equipment reset and central-

M232A1	Lot GDB07J-031014		

Standard MV	682
Δ Range per 1m/s	26
Gun MVV	-11.9
Expected MV	670.1

Elevation (15800m)	475.6
Δ Range per 1 mil EL	15

1 x PEr (50%)	2 x PEr (82%)	3 x Per (96%)	4 x Per (100%)
30 m	60 m	90m	120m

RNG	CHG	QE	MV	ADJ	Standard TFT values (verify computation procedures)				ΔMV	Δ Range from ΔMV	Adjusted Range from ΔMV	MV - ADJ AVG MV	Δ from Historical Measured MVV
					Adjusted Range	Δ Range from Δ QE	QE ADJ Range	ADJ vs QE Range					
15800	4H	497.9	665.6	-50	15800	0	15800	0	N/A	N/A	N/A	0	-4.5
		494.5	667.8	0	15750	-51	15749	-1	2.2	57.2	15807	3	-2.3
		494.5	658	200	15750	0	15749	-1	-9.8	-254.8	15495	-7	-12.1
		508.3	664.8	EOM	15950	207	15956	6	6.8	176.8	16127	0	-5.3

AVG MV	664.1	3	667.1
		-3	661.1

ADJ AVG MVV	665.2

* Note: Some values extracted from the TFT are not exact for the sake of speed and efficiency for this example but the results accuratly reflect the point of the table.

−9.8 m/s change in MV = 254.8 m decrease in range

6.8 m/s change in MV = 176.8 m increase in range

Figure 1. This figure shows the deviation in muzzle velocity. (Courtesy illustration)

ized fire support training program, all leaders and Soldiers were trained to maximize system capabilities, to include the loading of GPS communication security (COMSEC) keys into the Lightweight Laser Designator Rangefinder, loading precision imagery on the ruggedized handheld computer and standalone computer unit, target mensuration to refine target location, bore-sighting the Fire Support Sensor System and calibration of all target location devices.

The fire support tactical standard operations procedures were updated and operations on the observation post were refined to an exacting standard: observers self-locate using GPS with COMSEC, lase a target with a fully mission capable and calibrated device, refine that target location using Precision Strike Suite – Special Operations Forces (PSS-SOF) software, and obtain a height above ellipsoid altitude and process the mission over the digital Fires network. In the end, TLE was greatly reduced, thus allowing troubleshooting to focus on fire direction and cannon operations.

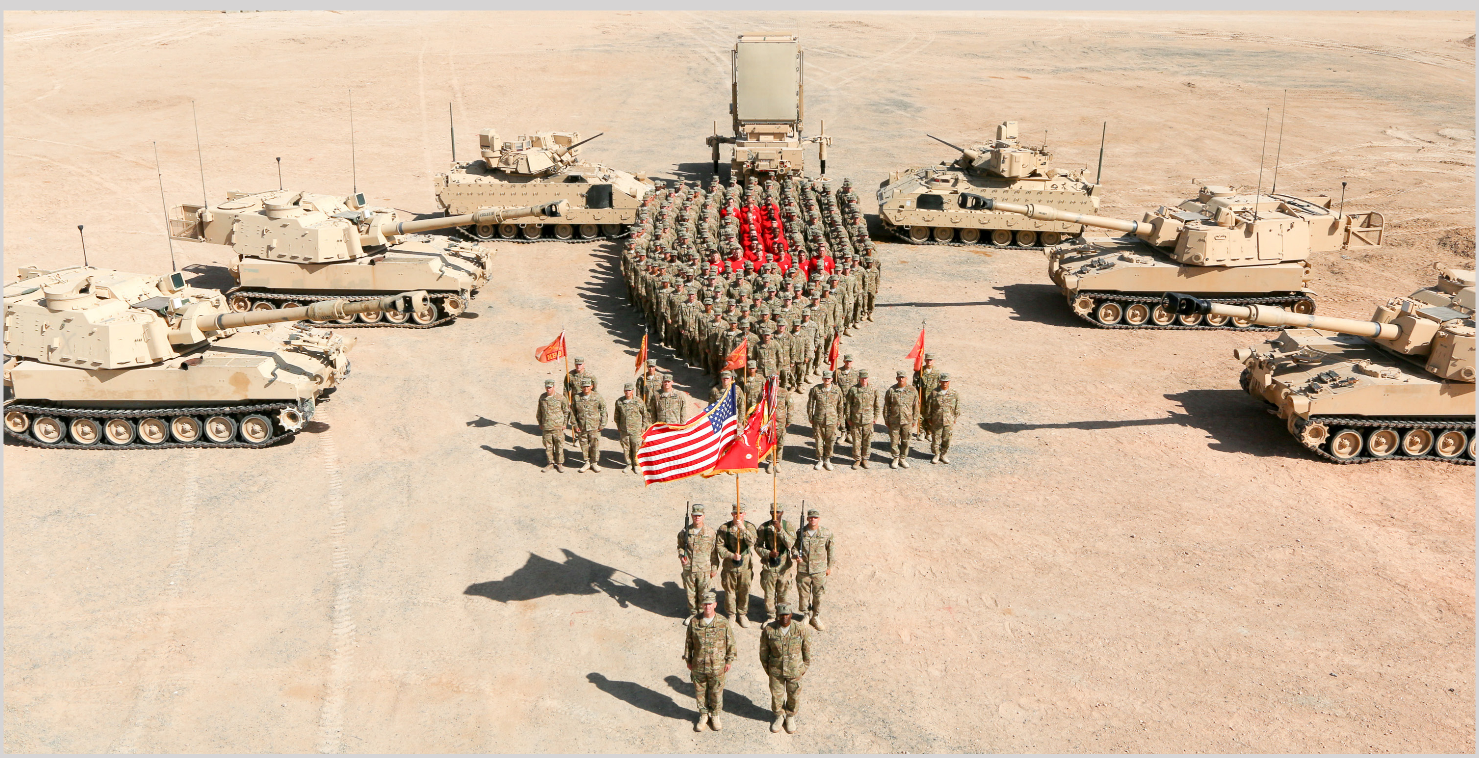
Characteristics that effect interior ballistics

In October 2015, B Battery, 1-7th FA deployed in support of Operation Inherent Resolve. Over a period of four months, 2nd Platoon, B/1-7th FA fired over 1,500 rounds in an environment where accuracy is of the upmost importance. As the months progressed, the platoon observed increased dispersion along the gun-target line – an "anomaly" that was isolated to only one platoon. Unmanned aerial surveillance platforms allowed us to observe and record the spotting from every mission (in some cases refine the impact grid using near-mensuration). This real-time feedback enabled troubleshooting.

We initiated troubleshooting associated with range errors. First, we compared the firing solution in the fire direction center as well as the command deflection/quadrant and actual deflection/quadrant in the Paladin Digital Fire Control System (PDFCS). We noticed an irregularity in the muzzle velocities on the PDFCS record of fire. The following chart outlines the data for one mission. The blue and red boxes highlight where the muzzle velocity increase or decrease directly affected the range. The standard muzzle velocity is highlighted in green for comparison.

The AFATDS was operating using the enhanced muzzle velocity (MV) mode, actively collecting and applying muzzle velocity data to the muzzle velocity variation (MVV) database. Therefore, range dispersion should have decreased with each mission fired. However, over 70 percent of the missions displayed erratic muzzle velocities that varied from 5-20 meters per second between rounds, resulting in errors in the range of 120-380 meters, increasingly outside of four probable errors in range.

The first step was to acknowledge this was not an unexplainable phenomenon. Our ability to correct the dispersion is not limited by science, but by our understanding. Gunnery can explain the dispersion. The battery and platoon leadership began to examine the 14 sub-categories of interi-



or ballistics that can account for non-standard velocities: velocity trends, ammunition lots, tolerances in new weapons, tube wear, non-uniform ramming, rotating bands, propellant and projectile temperatures, moisture content of the propellant, position of the propellant in the chamber, weight of the projectile, coppering, propellant residue, tube conditioning and two additional effects that include tube memory and tube jump.

In order to eliminate as many variables as possible we established a deliberate process to collect data:

1. Recorded muzzle MV readings from the PDFCS.
2. Video recorded crew drills.
3. Verified ammunition data including lots, square weight and temperature of propellant.

Through our analysis and logic, we considered then subsequently ruled out 13 variables of interior ballistics that account for non-standard velocities:

1. **Velocity trends.** The general increase of MV as additional rounds are expended does not explain positive and negative muzzle velocity fluctuations of this magnitude.
2. **Ammunition lots.** Only one lot of propellant was on-hand in the turret. All other lots were removed from the turret and stored in the ammunition holding area (AHA).
3. **Tolerance in new weapons.** Calibration of each howitzer accounted for all variances within each specific cannon tube. Additionally, the MVV caused by inconsistencies in tube manufacture remains constant throughout the life of the tube.
4. **Tube wear.** Tube wear results in a decrease in muzzle velocities, however does not contribute to inconsistent muzzle velocities.
5. **Non-uniform ramming.** Non-uniform ramming can result in increased dispersion along the gun-target line and therefore was identified as a potential factor. However, the hydraulic rammers in the M109A6 were fully mission capable and the replenisher gauge readings were within tolerance. Additionally, the video of the crew drills validated a consistent four-second ram.
6. **Rotating bands.** Bands being excessively worn and not imparting the proper spin on a projectile would result in dangerously erratic round performance.
7. **Propellant and projectile temperatures.** Ammunition was stored, handled and prepared correctly to ensure uniform propellant temperatures. Temperatures were updated each hour and there was never a deviation greater than three degrees between thermometers. In addition, according to Firing Table 155-AR-2, Table E for Charge 4H, M232A1, a 50-degree change in temperature is required for a 10 meter per second variance.
8. **Moisture content of propellant.** All propellant increments were inspected for abnormalities and moisture damage prior to uploading into the turret.
9. **Position of propellant in the chamber.** Video recording of crew drills validated propellant was positioned flush against the Swiss groove prior to closing the breech.
10. **Weight of the projectile.** Only four square projectiles were on-hand in the turret. All other projectiles were removed from the turret and stored in the AHA.
11. **Propellant residue.** Video recordings validated the number one cannoneer swabbed three times to the forcing cone and around the obturator spindle group until clean between each round. In addition, the tube was punched according to the technical manual after each mission or at a minimum each day and bore evacuators were cleaned weekly.
12. **Tube conditioning.** Tube temperature is correlated to a predictable range dispersion. Tube conditioning does not explain unpredictable range dispersion.
13. **Tube memory and tube jump.** The preponderance of missions were fired with charge 4H eliminating the likeness of tube memory. Additionally, the discrepancy was not limited to the first round of the mission.

Additionally, since we were obtaining random erratic muzzle velocities we were able to eliminate other factors that could result in range errors:

1. MET: Metrological data was verified in accordance with TC 3-09.81.
2. Looseness in the mechanics of the carriage: We surged a team of mechanics to the firing point to execute the annual service two months prior to the due date. No abnormalities were identified.
3. Limitations of setting values for deflection and quadrant: Although a Fire Control Alignment Test (FCAT) had not been done within six months, the offsets were input in accordance with the DA Form 2408-4.

After detailed analysis and an unscheduled borescope, coppering of the tube, the thin film of copper deposited in the tube when high charges are fired and high velocities, was identified as a possible explanation. The previous approximately 1,000 rounds were fired exclusively with 4H and 5H. Initially, coppering was not considered due to the daily tube maintenance which includes cleaning the tube with the basic issue brush. The borescope proved the bore evacuators were clean and that there were no signs of cracks or fractures, but did present initial signs of residue. Approximately one month later, an Ammunition Information Notice was published warning of residue build-up in tubes after expending a high volume of M232A1, charge 5. The message stated routine tube maintenance cannot extract or dissolve this residue. Firing a low charge of M231 is the only method to burn or "clean" the residue. After the publication of this message, we obtained authorization to execute fire missions at a reduced range with M231. Since then, the muzzle velocity variations are now within +/- 4 m/s, leading us to conclude that the firing of the lower charge effectively burned away the residue deposited in the cannon by repeatedly firing M232A1.

Through our efforts to analyze the error and account for every meter of inaccuracy outside of the probable error in range, we were able to improve accuracy, achieve higher rates of battle damage, and prove to young artilleryman the science of gunnery can explain every variable of ballistics.

Firing unit location

Also while firing in support of Operation Inherent Resolve, 1st Platoon, B/1 - 7th FA noted an abnormal range deviation. The platoon was meeting the five requirements for accurate fire, the rounds were within two probable errors in range but one M109A6 was out of sheaf due to a range error. The battery and platoon leadership began troubleshooting procedures. According to Appendix B "Troubleshooting" of TC 3-09.81, the factors that can affect range error are site, target/observer location, projectile square weight, propellant temperature, muzzle velocity variation, air temperature, air pressure, howitzer location, meteorological datum plane (MDP) altitude, wind direction, wind speed, quadrant elevation and charge.

In order to eliminate errors we again collected and analyzed data:

1. Recorded MV data from the AFATDS and PDFCS;
2. Ammunition data including lots, square weight and propellant temperature;
3. Documented the AFATDS firing solution and the actual and command deflection/quadrant from the PDFCS along with the firing data from the PDFCS "record of fire,"
4. Howitzer firing location and altitude.

Because the issue was isolated to one howitzer and not the entire platoon, we were immediately able to discount issues that would result in the error across the platoon.

1. All MET related issues: air temperature, air pressure, MDP altitude, wind direction and speed.
2. Target location and observer location error.

Additionally, after collecting and verifying data from the PDFCS and AFATDS we were able to eliminate other potential causes of error:

1. **Projectile square weight.** Only four square projectiles were on-hand in the turret. All others were removed to the AHA.
2. **Propellant temperature.** The deviation between thermometers was less than three degrees for the same propellant when tested with various thermometers. Additionally, propellant temperature was updated prior to each mission.
3. **Quadrant elevation.** All M109A6s were dry-fire verified. Command quadrant elevation matched actual quadrant elevation on the PDFCS record of fire for each Paladin and each mission.
4. **Charge.** Ammunition counts were conducted for each howitzer section after the missions in question to verify the correct charge was fired. In addition, the FDC calculated the mission for a higher and lower charge, discovering the magnitude of the error did not match.

Therefore, the error was isolated to site and/or howitzer location. Since the AFATDS calculates the site data based on the vertical interval, range and the complementary site factor, the only factors that could vary between howitzers is the vertical interval and range. First, we verified firing unit location for each M109A6 with a Defense Advanced GPS Receiver (DAGR). All howitzers were within the prescribed tolerances. However, although the howitzers were stationary, the FDO identified deviations of the howitzer location (reported using the digital piece statuses).

Projectile	M795
Charge (M231)	1L
TGT ALT (m)	42
Range (m)	5000
Elevation (mils)	379.1

Firing Unit ALT (m)		SI (mils)	QE (mils)	Actual Range (m)	Δ Range from Actual FU location (m)
Upper Limit	100	14.1	393.2	5129	42
Actual Location	81	9.5	388.6	5087	0
Lower Limit	62	4.9	384.0	5045	-42

Projectile	M795
Charge (M231)	2L
TGT ALT (m)	42
Range (m)	9000
Elevation (mils)	446.0

Firing Unit ALT (m)		SI (mils)	QE (mils)	Actual Range (m)	Δ Range from Actual FU location (m)
Upper Limit	100	8.0	454.0	9095	31
Actual Location	81	5.4	451.4	9064	0
Lower Limit	62	2.8	448.8	9033	-31

Figure 2. Calculations by the FDC with a difference of 19 meters in altitude from the howitzer produced an error of 42 meters at a range of 5,000 meters and 31 meters at a range of 9,000 meters. (Courtesy illustration)

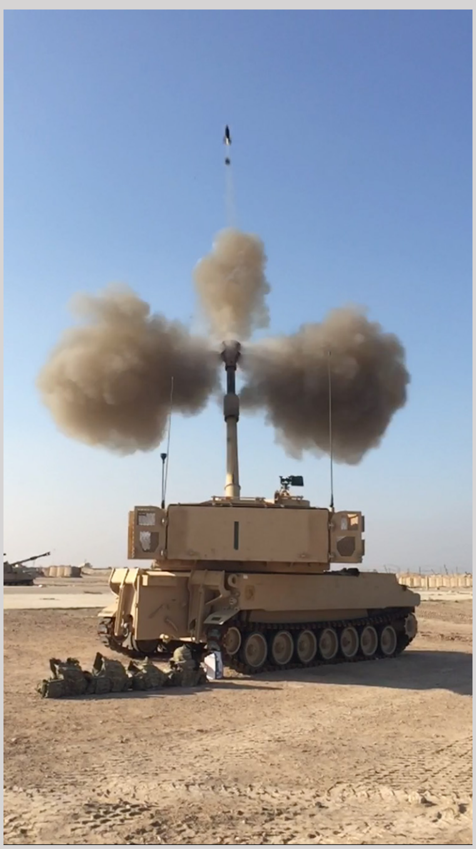
According to the M109A6 technical manual, "the PDFCS position has been observed to drift while the howitzer is stationary" and "these problems have been traced to errors in communications between the PDFCS and PDCU." It continues to state, "with the GPS receiver (DAGR) installed and the PDFCS operated in a GPS-aided mode, the problem will be bound to an acceptable level." In light of this known issue, all troubleshooting procedures outlined in TM 9-2350-314-10-2 were followed, but were unsuccessful in identifying a solution to the issue. Additionally, all M109A6s had black cryptographic keys loaded in order to be precision-guided munitions capable and no warning messages were observed regarding the GPS.

To verify the issue, we relied on the science of gunnery. Ten meters of error in the easting and northing equates to less than 14 meters of dispersion (regardless of range to target). The error associated with altitude is more pronounced – a 20 meter change in altitude contributes to error in the vertical interval and therefore site, which is a function of range. It was determined through calculations by the FDC (see tables below) that a difference of 19 meters in altitude from the howitzer produced an error of 42 meters at a range of 5,000 meters (M231 charge 1) and 31 meters at a range of 9,000 meters (M231 charge 2). The error decreases as the range to target increases.

Given this, if a howitzer reports its position at the upper limit within its tolerance (20 m) for altitude and an easting and northing that are both approximately 10 meters off from the actual location, the total error for M231 Charge 2 would be approximately 45 meters. Since we were trying to achieve the highest level of accuracy possible, this error, although within tolerance, can be minimized.

The leadership determined an immediate and a subsequent solution. First, three DAGRs operating in averaging mode established a firing unit location. The FDO, who was target mensuration-only qualified and trained on PSS-SOF, mensurated the location of the M109A6 based on the precision imagery available and real time video feed from a surveillance platform, then compared the results to the DAGR locations. Once verified through multiple means, this location was input into PDFCS. The battalion headquarters then deployed the battalion's organic survey assets into theater to achieve a greater order of survey. Once the corrections were made, the range error effecting the sheaf was eliminated.

A Paladin weapon system, from 1st Battalion, 7th Field Artillery Regiment, fires an Excalibur round during a live-fire exercise. (Courtesy photo)



Azimuth offsets

In January 2015, 1-7th FA replaced the M284 cannon tubes on 18 M109A6 Paladins. After the tubes were replaced a FCAT was conducted. Once complete, all DA Form 2408-4 and PDFCS offsets were updated accordingly. Approximately two weeks later, the battalion went to the field to seat the tubes. Multiple observers were employed to record the spottings. After the initial volleys and subsequent maintenance adjustments were complete, each platoon conducted three mass missions to verify sheaf. The observer team notified the battalion FDC that during one platoon iteration, one of the howitzers was out-of-sheaf and was consistently landing approximately 100 meters left of the target along the gun-target line. Troubleshooting procedures were initiated to discover the cause of the deflection error.

Again we collected the following data:

1. Howitzer locations.
2. Azimuth of lay.
3. Command deflection from the AFATDS and PDFCS, which was compared to the actual deflection recorded on the record of fire in the PDFCS for the missions fired.

Since the issue was isolated to one howitzer and not the platoon, we were able to discount issues that would result in the error across the battery.

1. All MET related issues: wind direction and speed.
2. Target location and observer location error.

Upon further investigation of PDFCS and AFATDS data, we eliminated numerous factors associated with a deflection error:

1. **Deflection.** All M109A6s were dry-fire verified. Command deflection matched actual deflection on the PDFCS record of fire for the Paladins.
2. **Azimuth of lay (AOL).** All M109A6s were confirmed to be laid on the proper azimuth of lay using an M2 compass as well as the tube-to-tube verification. Additionally, the AOL was verified to be correct in the AFATDS for each howitzer.
3. **Howitzer location.** All M109A6s locations were surveyed using the battalion's organic survey assets and the correct easting, northing and elevation was verified in the PDFCS and AFATDS.

Of course, logic is important for effective troubleshooting, specifically, to focus the data collection – what has changed since the last live fire? Since we had just completed tube replacement then subsequently FCAT on all the howitzers, all units were directed to verify PDFCS maintenance offsets to compare data in PDFCS and 2408-4. Upon verification of the offsets, it was identified that the azimuth offset was input incorrectly into the PDFCS. The chief of section entered 11.2 instead of 1.2 into the azimuth offset. The mathematical calculation confirmed that the discrepancy accounted for 108 meters of error which is well outside of four probable errors in deflection for the propellant type and charge.

Conclusion

These vignettes outline incidents that are specific to 1st Battalion, 7th Field Artillery in which senior non-commissioned officers and junior officers identified, isolated then subsequently resolved errors. Our efforts were not hindered by expertise, but initially hindered by the reluctance to acknowledge error. We have matured to an organization that once defined success as "round observed safe" to an organization that examines every mission outside of a predetermined probable error in range/deflection. We continue to further our efforts to create a culture of leader development and professionalism that tries to account for every mil and every meter of error.

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