The History of U.S. Army Firing Tables Development

The Early Years

The origins of firing table development within the U. S. Army can be traced to the beginning of the United States' involvement in World War I. At the time three Army officers (CPT E. M. Ayer, LT R. H. Kent, and LT S. W. Alexander) were responsible for a variety of ballistic test duties; among them was the computation of firing tables. As WWI worn on, the demand for firing tables and other ballistic data increased so rapidly that the Army's Chief of Ordnance found it necessary to set up a special organization to accomplish this work. On April 6, 1918 he created the Ballistics Branch under his office. The first Head of the branch was Major F. B. Moulton, a former Astronomy professor at the University of Chicago. Under his leadership the branch expanded rapidly laying much of the foundation by which the science of ballistics advanced in the next two decades. Major Moulton added a number of well-known scientists to his staff to conduct a variety of experiments in ballistics. Concurrent with the beginning of firing table development and the U.S.'s involvement in WWI, Congress decided to move the ordnance testing facilities from Sandy Hook, NJ to Aberdeen, MD. This was due primarily to Sandy Hook's limited range capabilities. The transition began at the end of 1917, and by January 2, 1918 the first test round was fired at what is now Aberdeen Proving Ground. Nine divisions were eventually established at the new proving ground comprising the Proof Department. The ballistics work was primarily assigned to three sections: Range Firing, Development, and Instrument. The Range Firing Section under MAJ Oswald Veblen prepared all firing tables, performed mathematical analyses of ballistic problems, and conducted experiments designed to increase projectile range and accuracy. The organization of the Proof Department remained unchanged until July 1922.As might be expected, when WWI ended a reduction in the number of personnel occurred. Other changes were also evident along the lines of reorganization of functions. In 1925 the Mathematical Unit of the Ballistic Section, Gun Testing Division, Proof Department, was assigned the responsibility of preparing ballistic and firing tables. Under this organization ballistic research continued at a surprisingly high level, despite funding and personnel limitations. By 1935 the first major reorganization of the period between the wars occurred. The Ballistic Section was withdrawn from the Gun Testing Division and established as the Research Division. COL H. H. Zorning was the chief of the Ballistics Section at the time and is credited with this move forward. The new Research Division of 30 people was organized into 6 sections. Two of the sections were involved in the development of firing and bombing tables. The Exterior Ballistics Section studied trajectories and flight characteristics of projectiles and bombs. The results of this section's work were used as the basis for computing firing and bombing tables and for designing new projectiles. The Computing Section prepared the firing and bombing tables for standard ammunition and bombs, computed fundamental ballistic tables, and prepared ballistic data to be used in improving fire control equipment. In December 1938 the Research Division was renamed the Ballistic Research Laboratory (BRL). Neither its mission nor organization changed. COL Zorning became Director of the Laboratory.

The Advent of the Computer Age

The development of the Bush Differential Analyzer in the early 1930s by Dr. Vannevar Bush of MIT greatly reduced the burden of firing table computation. The new machine was ready for use at Aberdeen Proving Ground by 1935 and was used to solve differential equations by means of mechanical integration. Two substantial advantages were its speed and accuracy. The success of the Bush Differential Analyzer marked the beginning of the development of specialized computers for ballistic computations. As often occurs, shortly thereafter the Bush Differential Analyzer was unable to keep up with the volume and scope of work it was called upon to do. Accordingly, the BRL arranged to have access to a larger analyzer of the same type in the Moore School of Engineering at the University of Pennsylvania. At the same time, considerable progress was made in substituting electrical for mechanical components in the new analyzer to obtain greater speed of operation and accuracy. In 1937 COL Zorning pursued the possibility of using electrical calculating machines for ballistic computation. Members of the BRL staff visited the IBM Corporation in 1938 to compare a firing table calculated automatically with one computed by the older method. The IBM table was found to contain only a few insignificant errors. This led to the decision to procure punch-card machines for ballistic work. However, funding shortfalls precluded the acquisition of the equipment until 1941, at which time they were used almost exclusively for firing table development. IBM later developed a relay calculator that added and subtracted at twice the speed of the standard punch-card machine and did multiplication three times faster. World War II caused an inordinate need for firing tables. To address this need, firing table computation became a round-the-clock job. Large rooms were filled with mostly women performing numerical integration calculations on hand crank calculators. Each trajectory involved multiple numerical integrations. Each range in a firing table required multiple trajectories. Each firing table required hundreds, if not thousands, of trajectories. Therefore, to compute a complete firing table with multiple charges, it likely required millions of individual calculations. Even with these great advances in computer and calculating technology, the need for increased computing speed, better accuracy and flexibility of operation was evident, particularly as World War II progressed and the demand for firing and bombing tables increased. Two computers were designed during the latter part of WWII to address this need. Unfortunately, their development and completion were not realized until after the war. The ENIAC (Electronic Numerical Integrator and Computer) and EDVAC (Electronic Discrete Variable Computer) were built by the Moore School of Engineering at the University of Pennsylvania. ENIAC's development marked the beginning of the computer age, as we know it today. It is interesting to note that the computer age was spawned because of a need to quickly and efficiently compute the trajectories that were required for firing tables. The installation of the ENIAC in 1947 at the BRL marked the beginning of widespread use of electronic computing machines. Follow-on computer development resulted in firing tables being calculated with in-house BRL designed systems such as, ORDVAC and BRLESC. The second version of the Ballistic Research Laboratory Electronic Scientific Computer (BRLESC II) was still being used to compute trajectories and solve other scientific problems in the late 1970's. Eventually, computer technological improvements in the areas of capacity, speed, and accuracy exceeded the requirements for typical firing table development. Therefore, the need for BRL in-house developed computing devices ceased, and firing tables were then produced on commercially available hardware.

The Progression to the Present

After WWII ended the Army and Air Force were divided into two distinct services. Likewise, the firing tables and bombing tables were divided into separate entities. The bombing table mission was re-located to Eglin Air Force Base in Florida while the firing table mission remained at Aberdeen Proving Ground, Maryland. The normal progression would have been toward a reduction in firing table emphasis and personnel after WWII. However, with the advent of the Cold War, the Korean Conflict in the early 1950s, and Viet Nam War in the 1960s, the need for firing tables and general ballistic work was continuous. Once computers arrived on the scene, the advancements in computing technology occurred with great regularity. However, computing capability was only one part of the process for developing firing tables. Another area that needed improvement was the trajectory model that simulated the projectile's flight path. In the 1960's work was begun to upgrade the trajectory model, which until that time was basically a point mass, or particle, trajectory simulation. This rudimentary simulation required add-on terms to account for projectile drift, which was a result of rounds using spin for stabilization purposes. A modified point mass mathematical model, which incorporated an estimate of the yaw of repose, was developed by Robert Lieske and Mary Reiter in March 1966. It was developed to better represent the flight of spin-stabilized, dynamically stable artillery shell. Through the 40 years since it inception, a variety of modifications have been made to the modified point mass (MPM) model to allow for simulation of direct fire rounds, base-burn shell, and rocket assisted projectiles, to name a few applications. This model is known world-wide, is often requested, and serves as the basis for the NATO standard in the area of ballistic fire control. A firing table methodology breakthrough resulted primarily because of the development of the modified point mass trajectory model. The more accurate MPM simulation allowed for a reduction in the number of rounds required to develop firing tables. In addition, the use of interior ballistic modeling techniques to address muzzle velocity issues related to propellant temperature and projectile weight variations helped reduce the number of test rounds that needed to be fired to accumulate these data. Further improvements were seen in the areas of test design and aerodynamic coefficient development. These methodology improvements resulted in the savings of countless development dollars without sacrificing the accuracy of the firing table. The improved exterior and interior ballistic modeling methodologies, the advancements associated with aerodynamic development, and the improved computing capability, all served to produce more accurate firing tables. By the 1970's advancements in computing technology had made it feasible for computing devices to be used in a field environment, i.e., training and combat. The first field computers were unsophisticated by today's standards; however, they were great technological advancements for their time. The Field Artillery Digital Automatic Computer (FADAC) numerically integrated the point mass equations of motion and used an add-on polynomial fit for the calculation of drift. Tank and helicopter ballistic computers used fitting techniques to incorporate the data contained in the firing tables into their respective fire control computers. In some sense they were basically large calculators that crunched polynomial fits of the data contained in the firing table to point the tube.As computing technology continued to improve through the 1970's and 1980's, the level of sophistication regarding field computers improved also. Miniaturized components allowed for smaller devices. Additionally, the speed with which the computations were made increased dramatically. Once computational speeds reached acceptable levels, and the devices became small enough with sufficient memory and storage capability, it became feasible for field computers to solve the equations of motion that simulate projectile flight rather than use polynomial fitting techniques. This process provided more accurate gunnery solutions. By this time, the Firing Tables Branch, as it was known at the time, was providing the databases and computational methodologies for field computers such as TACFIRE (Tactical Fire) and the Battery Computer System (BCS) for artillery applications. Similar work was being done to support fire control computers associated with tank, helicopter, and mortar weapon systems, as well. During the early 1990's the Firing Tables Branch (now the Firing Tables and Ballistics [FTaB] Division) and the Forsvarets Forshningsinsitutt (FFI) of Norway started planning the next generation of ballistic processing for field artillery technical fire control systems. The advancements in computing speed and memory size along with the flexibility of new programming languages made the idea of a standard, generic, and layered set of software modules for ballistic processing an attractive feature to the NATO AC/225 Panel IV, Sub-Panel 2 (now Land Capabilities Group 3 on Fire Support, Sub-Group 2) on Ballistics. The FTaB chief has been the chairman of that NATO sub-group since the 1970's. Hence, FTaB represented the U.S. as a co-lead (with FFI of Norway) in the development of a NATO Armament Ballistic Kernel (NABK).Currently, 15 NATO nations are participating in this effort and are implementing, or plan to implement, country-specific versions of the NABK in their artillery fire control systems. The NABK was designed and developed with sharability and reusability of software modules in mind. On the battlefield the NABK will be used for all ballistic processing that requires trajectory and muzzle velocity simulations and will be a key factor in allowing ammunition interchangeability among NATO nations during multinational training and combat exercises. The first application of the ballistic kernel (BK) methodology was its inclusion in the Improved Mortar Ballistic Computer (IMBC) in May 1995. Subsequent versions of the IMBC BK were developed and released for new and improved munitions and incorporated into the Mortar Fire Control System (MFCS). The experience gained and lessons learned during the IMBC BK development were instrumental during the NABK effort. Another recent, highly visible and significant effort within FTaB is that associated with the Meteorological, or Met, Kernel. The met kernel is a weather forecasting model that will allow accurate weather predictions while minimizing the need for labor intensive, time-consuming, and expensive met collection currently accomplished with weather balloons. The most important factor associated with correctly generating a gunnery solution is knowing the weather conditions through which the projectile will fly. Over the last several years FTaB has worked diligently with the NATO community and academia to develop, implement and test various prototype versions of the met kernel. In 2003 FTaB participated in an international live-fire test exercise that was conducted in Denmark along its western coast to evaluate competing met kernel methodologies. Additional testing is planned in 2006 in Turkey's high desert to assess the met kernel's reliability at forecasting weather data for that terrain. Still further, future testing is planned for southern France to provide yet another terrain data sampling relating to the met kernel's proficiency in a different weather environment. Because of their involvement in international forums (e.g., NATO, ABCA, The Technical Cooperation Program, and the Joint Ballistic Working Group), FTaB has become a training ground for many foreign scientists desiring to learn the methods of firing table data reduction and analysis, software development and conduct ballistics studies. At one time or another during the past 25 years, FTaB has hosted and/or trained personnel from Australia, Belgium, Canada, Denmark, France, Germany, Greece, Italy, Japan, Norway, South Korea, Turkey, and the United Kingdom. Conversely, Firing Table and Ballistics personnel have had the opportunity to travel to most of the aforementioned countries for meetings or test exercises. In the area of artillery delivery accuracy, FTaB has designed and participated in a series user tests since the late 1970's. These tests were conducted with Army and Marine Corps units under quasi-combat conditions and have served to provide an accuracy database for the predicted fire and registration/transfer delivery techniques. Results from testing in the early and mid 1990's have validated the theory that the largest accuracy error sources can be attributed to not knowing the weather conditions precisely enough. The FTaB has participated in another area of delivery accuracy, as well. For more than 20 years FTaB personnel have been significant contributors, working in conjunction with the U.S. Army Materiel Systems Analysis Activity (AMSAA), toward the development and refinement of artillery models for predicting ammunition/weapon precision and accuracy. These models have become the standard by which groups, such as the Joint Munitions Effectiveness Manual (JMEM) and the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME), have generated their accuracy estimates and based their conclusions on weapon system's accuracy and effectiveness. In late 1992 the Ballistic Research Laboratory was re-organized and absorbed into the Army

Research Laboratory in an effort to gather all of the U.S. Army's research laboratories under one umbrella. Perhaps fittingly, the firing table mission, the primary reason for the formation of the BRL in 1938, was re-assigned in-place to the Army's Armament Research, Development and Engineering Center (ARDEC) headquartered at Picatinny Arsenal, NJ. This effectively ended the era of firing table development at the BRL.Currently, the Firing Tables and Ballistics Division contains 21 employees who are supervised by Robert F. Lieske. Over its long and illustrious history FTaB has employed a multitude of professional engineers and scientists of varying job descriptions, including, but not limited to: mathematicians, statisticians, ballisticians, operations research analysts, aerospace engineers, computer scientists, physical scientists, artillery specialists, military officers and enlisted personnel. With a responsibility for the development of firing tables and other aiming data related products, such as ballistic fire control data and ballistic kernels (fire control software for fielded weapon systems), as specified by Army Materiel Command regulation, the FTaB is divided into two teams to accomplish its mission: the Aiming Data Technology Team, and the Ballistic Software Engineering Team. The Aiming Data Technology Team is led by Mr. James Matts and has the responsibility for developing a variety of aiming data products. Among these are tabular firing tables (TFT), graphical firing tables (GFT), graphical sight tables (GST), and electronic firing tables (eFT). Electronic firng tables have recently been incorporated into the Army Knowledge Online (AKO) website and have been very favorably received by combat soldiers and Marines. Some other duties of the Aiming Data Technology Team are interior ballistics methodology and generation of aerodynamic and ballistic parameters for firing table development, delivery accuracy estimates and theory, and foreign ammunition exploitation. The Ballistic Software Engineering Team is led by Mr. Jon Miller and has the two basic responsibilities: ballistic kernel (BK) development and the enhancement of subsequent BK versions in addition to internal software generation and maintenance. In the area of ballistic kernel development the software team continues to work with the U.S.'s NATO allies to improve and expand the NATO Armaments Ballistic Kernel (NABK), having recently fielded version 8.0. Derivative ballistic kernels for U.S. specific weapon systems continue to be developed, enhanced and maintained. Internal software codes, such as the various trajectory models and the firing table manuscript preparation tools, are maintained and modified, as needed. When new ballistic technologies are developed, the software team undertakes the task of producing reliable code to describe the bullet's flight path. In the recent past the software team has begun training other government agency personnel, contractors and foreign computer scientists in the areas of ballistic kernel software creation, database design, documentation, and quality assurance test procedures.

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