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Generation of Artillery Firing Tables for The L119 Howitzer with Base-Bleed Projectiles

Abstract

This paper describes the process that we have performed in generating firing tables for the L119 Howitzer with base-bleed extended range projectiles. The process involves four main steps, which are determining projectile coefficients, selecting the desired trajectory model, implementing the model and verifying the generated results. In determining projectile coefficients, we employed several tools such as CFD (Computational Fluid Dynamic) and Aerolab. The model that we selected is the modified point-mass model because of its high accuracy without too much of computational requirements. We were able to complete the generation of all 13 artillery firing tables by using a regular notebook computer within half an hour. Finally, our generated firing table for the L119 Howitzer with base-bleed project was able to achieve 80-meter accuracy for a 9,500 m firing range, which is very accurate for a howitzer with extended-range projectiles.

1. Introduction

Generation of accurate firing tables for howitzers are very important to the artillery. The calculation involves many assumption and parameters such as the assumed dynamics of the projectile, the environments and the projectile's characteristics. In this paper we will focus on one specific howitzer, the L119, which is manufactured by the Weapon Production Center in Lopburi. The L119 is a light weight, helicopter transportable, air droppable (by parachute) towed Howitzer. Its picture is depicted in **Figure 1.** with the specification in **Table 1.**

Figure 1 The L119 Howitzer

Table 1 Technical Specification for the L119 Howitzer

Feature	Specification
Type	Towed howitzer
Weight	1,940 Kg
Length	16Ft.
Width	5 Ft. 10 in.
Crew	5 - 7
Caliber	105 mm.
Elevation	-100 to +1250 mils
Traverse	Left or Right 100 mils
Barrel	right-hand twist rifling
	(1 turn in 18 calibres))
Rate of Fire	8 rounds per minutes for 3 minutes.
Maximum Range	11.5 km (Charge 7), 19.5 km (rocket-assisted projectile)

2. Related Background Theory

2.1 Firing Tables

Field artillery needs to use firing table to calculate the required elevation angle of the howitzer in order for the projectile to achieve the given range. There are 10 tables in the firing table as shown in Table 2. Note that Table F contains fundamental information for artillery firing.

Table 2 List of Table for Artillery Firing Tables

Table Code	Table Name
Table A	Line numbers of meteorological message
Table B	Complementary range and line numbers of the meteorological message
Table C	Components of a one knot wind
Table D	Air temperature and density corrections
Table E	Effects on muzzle velocity due to propellant temperature
Table F	Basic data and correction factors
Table G	Supplementary data
Table H	Corrections to range in metres to compensate for the rotation of the earth
Table I	Corrections to azimuth in mils to compensate for the rotation of the earth
Table J	Fuze correction factors

2.2 Atmosphere Modeling

Temperature, pressure, and air density can affect the trajectory of the howitzer's projectile. In order to calculate the trajectory, one needs to have a "standard" atmosphere where all calculations are based upon. Each trajectory model can then provide adjustment mechanism to compensate for the change in atmosphere. To further simplify the calculation process, it is also desirable to have this standard atmosphere close to the actual atmosphere that will be used to fire the projectile. The standard that we used in our calculation is the ICAO (International Civil Aviation Organization) standard, which is the most widely used standard in trajectory calculation. This standard assumes a sea-level temperature of 15 ^{o}C, a pressure of 1,013.25 mbars and an air density of 1.225 kg/m^3 The temperature in this model decreases at the rate of 6.5 ^{o}C per km up to the altitude of 11 km. After this height, the temperature in the model remains constant at -56.5 ^{o}C.

2.3 Trajectory Modeling

Trajectory model is a mathematical model that describes the motion of the projectile starting from the howitzer's muzzle to its termination. Several trajectory models have been devised. Some models can be solved analytically, while others require numerical method to solve it. An important characteristic of a trajectory model is its accuracy; other desirable characteristics of the model are its simplicity and computational requirements. We will briefly describe four trajectory models in this paper, starting from the least complex to the most complex one.

2.3.1 The Vacuum Model

This model assumes that the projectile travels in vacuum and also neglect the aerodynamic forces and moments that act on the projectile. The result is a simple high-school trajectory model. This model can be used as a reference to check the result of calculation from other models. That is the trajectory of other models is bounded by the vacuum model. The model is relatively accurate for short-range firing and low-drag projectile.

In this model, the needed angle of elevation (ϕ_0) for the desired range (R) can be analytically obtained from

$$\phi_0 = \frac{sin^{-1}(\frac{gR}{v^2})}{2}$$

Where g is the acceleration due to gravity and v is the muzzle velocity.

2.3.2 The Point-Mass Model

This model assumes that all the projectile mass is located at a single point. This model also accounts for the drag caused by the air, but like the vacuum model, it neglects the aerodynamic forces and moments that act on projectile. The trajectory is given by the following set of equations

$$\frac{d^2x}{dt^2} = -\frac{\pi\rho d^2 C_D}{8m} v\left(\frac{dx}{dt} - Wx\right)$$

$$\frac{d^2y}{dt^2} = -\frac{\pi\rho d^2 C_D}{8m} v\left(\frac{dy}{dt} - Wy\right)$$

$$\frac{d^2z}{dt^2} = -\frac{\pi\rho d^2 C_D}{8m} v\left(\frac{dz}{dt} - Wz\right)$$

Where ρ is the air density, d is the projectile diameter, C_D is the drag coefficient, m is the projectile mass, is the range, y is the height, z is the drift, Wx, Wy and Wz are wind velocity for the three axes .

This model is fairly accurate and has been used by manufacturers to generate firing tables for some period of time.

2.3.3 The Modified Point-Mass Model

Just like the point-mass model, this model assumes that all of the projectile mass is located at a single point. However, the modified point-mass includes effects of the aerodynamic forces/moments and also the effect of the Earth's rotation while the projectile is travelling in the air. This results in a very accurate model and is the standard model being used to generate firing tables. The model is represented by the following set of ordinary differential equations

$$\frac{du}{dt} = -\frac{\pi\rho d^2}{8m}\left(C_{D0} + C_{D_{\alpha^2}}\alpha_r^2\right) v\mathbf{v}$$
$$+\frac{\pi\rho d^2}{8m} C_{L_\alpha} v^2 \boldsymbol{\alpha}_r$$
$$-\frac{\pi\rho d^3}{16m} C_{Y_{p\alpha}} p(\boldsymbol{\alpha}_r \times \mathbf{v})$$
$$-g_0 \frac{R^2}{r^3}\mathbf{r} + 2\,(\boldsymbol{\omega} \times \mathbf{u})$$

$$\frac{dp}{dt} = \frac{\pi\rho d^4}{16\, I_x}\, pvC_{l_p}$$

$$\boldsymbol{\alpha}_r = \frac{8pI_x}{\pi\rho d^3 C_{M_\alpha}} \frac{\left[v \times \frac{du}{dt}\right]}{v^4 \alpha_r}$$

Where

$$\boldsymbol{u} = \frac{d\boldsymbol{x}}{dt},\ \ \mathbf{v} = \boldsymbol{u} - \boldsymbol{W},\ \boldsymbol{r} = \boldsymbol{x} - \boldsymbol{R},$$

$$\boldsymbol{R} = (0, -R, 0)$$

$$\omega = (-\Omega\ \cos[lat]\cos[azimuth],$$
$$-\Omega\ \sin[lat],\ -\Omega\ \cos[lat]$$

$\Omega = 7.29 \times 10^{-5}$ rads/s (Rotation of the Earth)

R = 6370320 m (Radius of the Earth)

g_0 = 9.80665 [1-0.0026373 cos(2 latitude) + 0.0000059 [cos (2 latitude)]^2

Where is the instant speed of the projectile, g_0 is the acceleration dues to gravity, is the axial spin rate, and is the projectile's moment of inertia about the x axis.

This model has been widely used in both offline (such as generating the firing table) and online (re-compute the desired output every time there is a need for it) calculation of the trajectory. One of the platforms that use this model is NATO NABK (Nato Armament Ballistic Kernel), which is a software component that aims to standardize and reduce the effort of developing ballistic fire control-related applications among member countries.

2.3.4 The Six Degree of Freedom Model

This model is the most complex and most accurate of all trajectory models; however, because of uncertainties in measurement of the input variables, aerodynamic coefficients and environments usually cause the model not to have much better accuracy than that of the modified point-mass model. The use of this model is therefore limited in the firing table generation.

2.4 Base-Bleed Projectiles

Base-bleed projectiles are designed to extend the range of normal projectile by removing the vacuum at the end of the projectile while it is traveling rapidly in the air. The vacuum at the tail is one of the major factors that increase the drag force of the projectile. To remove this vacuum, a small gas generator is added to the shell and generates gas that fills this vacuum. It does not attempt to thrust the projectile because that would require a larger power source. Base-bleed projectiles have shown to increase the range of fire by as much as 30%.

For our problem of generating firing tables for the L119, we do have firing tables for L119 with normal projectile; the table for base-bleed projectile is what we are trying to generate.

3. Implementation

The whole process that is used in generating the firing table is shown in **Figure 2.**

A model generator generates 3D model from 2D drawing of the projectile. This 3D model is then imported to CFD-GEOM to generate the mesh file (.dtf) that can be used for simulation by the CFD-ACE application. CFD-ACE runs the simulation by firing the projectile at the given muzzle velocity and angle of attack. It then generates a report indicating values of forces and moments that affect the projectile. These values are used to compute aerodynamic coefficients. The drag coefficient is separately computed by Aerolab. Once all coefficients are obtained, the Matlab application calculates the trajectory according to the modified point-mass model. Since the equations of modified point-mass are given in the form of ordinary differential equation (ODE), we will need to integrate it using numerical techniques. Fourth-Order Runge-Kutta integration method was used. Once the trajectory is obtained, the data is written to the database in the form of Table A to Table J, which can be immediately retrieved by the user interface system for display of the value to the user. The database engine employed is a MS Access database. Figure 3 to 6 show results obtained from major processes described earlier.

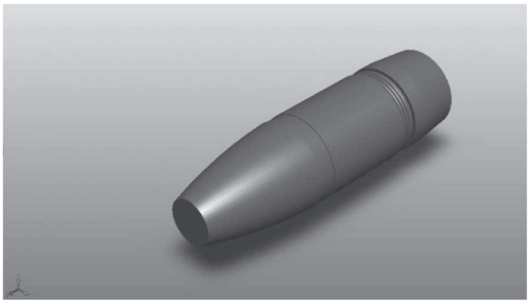


Figure 3 3D Model output of the 3D Model Generator

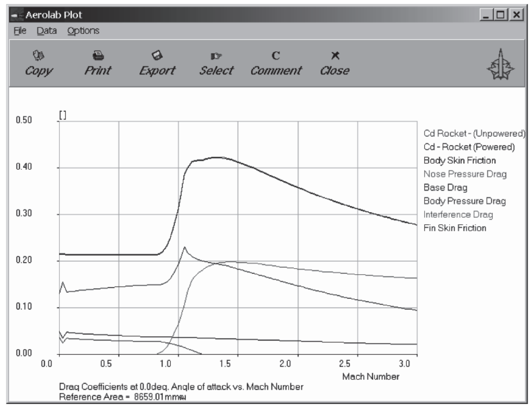


Figure 4 Aerodynamic Coefficients as a Function of Mach Number

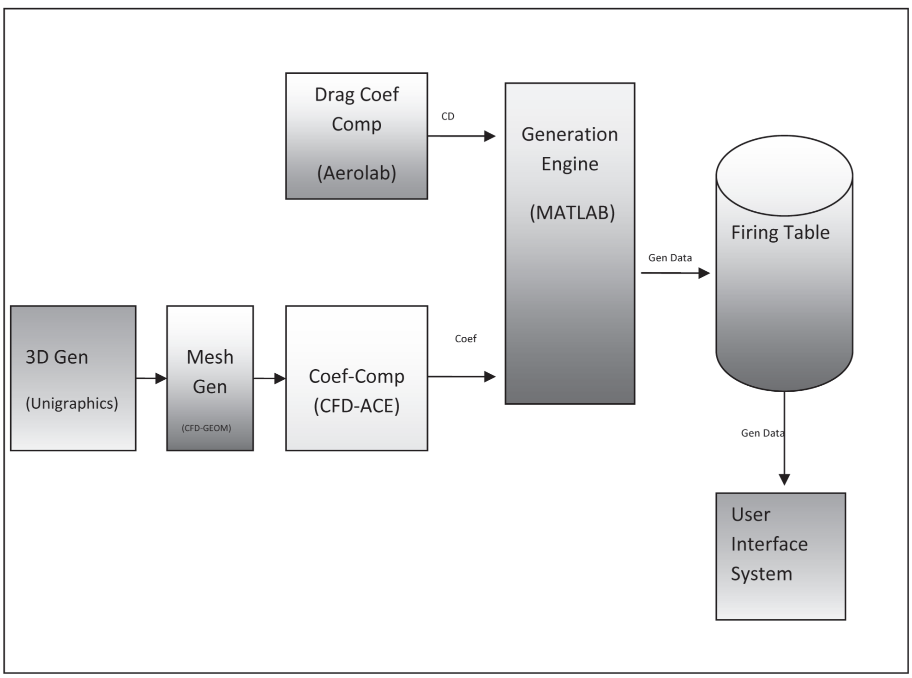


Figure 2 Firing Table Generation Process

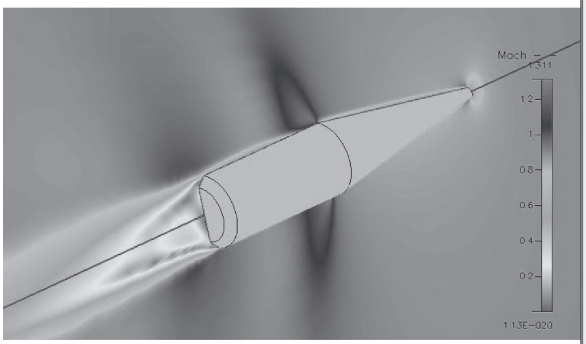


Figure 5 Simulation of the Moving Projectile to Obtain Acting Forces and Moments

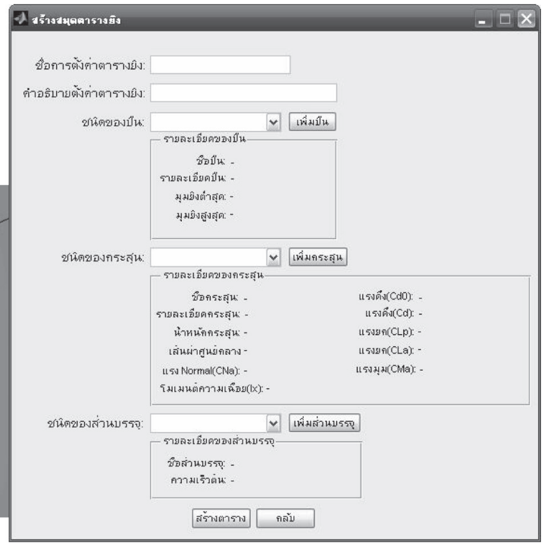
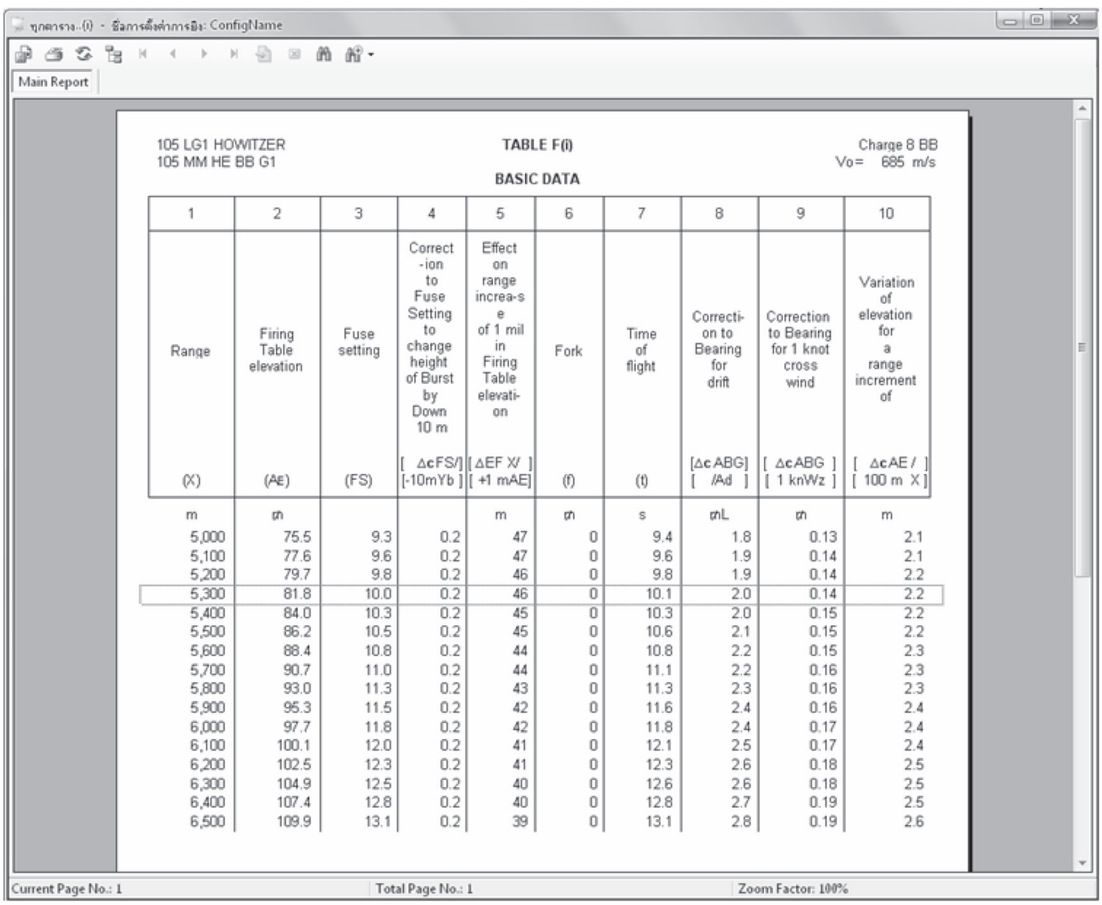


Figure 6 The User Interface Application for Requesting Firing Table



105 LG1 HOWITZER
105 MM HE BB G1

TABLE F(i)

BASIC DATA

Charge 8 BB
Vo= 685 m/s

1	2	3	4	5	6	7	8	9	10
Range (X)	Firing Table elevation (Aε)	Fuse setting (FS)	Correct-ion to Fuse Setting to change height of Burst by Down 10 m [ΔcFS/] [-10mYb]	Effect on range increa-se of 1 mil in Firing Table elevati-on [ΔEF X/] [+1 mAE]	Fork (f)	Time of flight (t)	Correcti-on to Bearing for drift [ΔcABG] [/Ad]	Correction to Bearing for 1 knot cross wind [ΔcABG] [1 knWz]	Variation of elevation for a range increment of [ΔcAE /] [100 m X]
m	ɱ			m	ɱ	s	ɱL	ɱ	m
5,000	75.5	9.3	0.2	47	0	9.4	1.8	0.13	2.1
5,100	77.6	9.6	0.2	47	0	9.6	1.9	0.14	2.1
5,200	79.7	9.8	0.2	46	0	9.8	1.9	0.14	2.2
5,300	81.8	10.0	0.2	46	0	10.1	2.0	0.14	2.2
5,400	84.0	10.3	0.2	45	0	10.3	2.0	0.15	2.2
5,500	86.2	10.5	0.2	45	0	10.6	2.1	0.15	2.2
5,600	88.4	10.8	0.2	44	0	10.8	2.2	0.15	2.3
5,700	90.7	11.0	0.2	44	0	11.1	2.2	0.16	2.3
5,800	93.0	11.3	0.2	43	0	11.3	2.3	0.16	2.3
5,900	95.3	11.5	0.2	42	0	11.6	2.4	0.16	2.4
6,000	97.7	11.8	0.2	42	0	11.8	2.4	0.17	2.4
6,100	100.1	12.0	0.2	41	0	12.1	2.5	0.17	2.4
6,200	102.5	12.3	0.2	41	0	12.3	2.6	0.18	2.5
6,300	104.9	12.5	0.2	40	0	12.6	2.6	0.18	2.5
6,400	107.4	12.8	0.2	40	0	12.8	2.7	0.19	2.5
6,500	109.9	13.1	0.2	39	0	13.1	2.8	0.19	2.6

Figure 7 The Generated Firing Table

4. Results

After developing the application, we tested the accuracy of the application by actually firing the base-bleed projectiles from the L119 howitzer. Since base-bleed projectiles are expensive and require long preparation period before it can be used (ie., they need to be submerged in water for 24 hours before use), we fired only three cartridges and obtain the result as shown in **Table 3.** As can be seen from the table, out of three rounds, there is only one round that can be used to analyze the effectiveness of the model and its implementation. An 80-meter error for a 9,500-meter range of fire (about 0.84%) is relative small compared to large number of factors that can lead to inaccuracies. Those factors include assumption factors (point mass projectile, homogeneous atmosphere, constant wind speed, constant barrel whorl), input measurement factors (powder temperature, wind speed, air density, muzzle velocity, etc.) and implementation factors (Runge-Kutta method, bisection method and floating-point representation). However; this encouraging result still needs more proof because we have fired very limited number of rounds.

Table 3 Results from the Firing Experiment

Round #	Result	Comment
1	719 m/s muzzle velocity was measured	Need to find the muzzle velocity first.
2	-	Unable to locate the hit
3	80 meters away from the target.	Distance is 9,500 m. (0.84% Error)

5. Conclusion

Generation of firing tables is a complicate and error-prone process. However, our initial experiment shows that satisfactory accuracy can be obtained by using a combination of reliable techniques such as the modified point-mass model, the fourth-order Runge-Kutta technique, and external ballistic simulation.

Overall, this project shows some evidence that the Army can have more self-reliance in the area of trajectory calculation which can lead to more freedom in weapon construction. Currently, there are some military projects that are triggered/augmented by this project, such as firing table generation for other types of howitzers and artillery fire control systems.

Credits

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