

Chapter 2 Evolution of the Siege & Cannon Analysis

2.1 Evolution of the Siege

2.1.1 American and British Objectives

Success for both sides was completely dependent on artillery as the battle unfolded. The British had guns spread throughout their outer line but the Americans needed to specifically disable those at Card's Redoubt and the 7 and 10-gun batteries (Figure 2.1), which protected the south end of the battlefield (Figure 2.2, left side). If this could be accomplished, they could safely cross the swamped valley and turn the guns of the British southern flank against the rest of the line. The British firing back needed to do everything in their power to prevent this. Despite cannonading the enemy for days, the Americans failed to disable their three main targets.

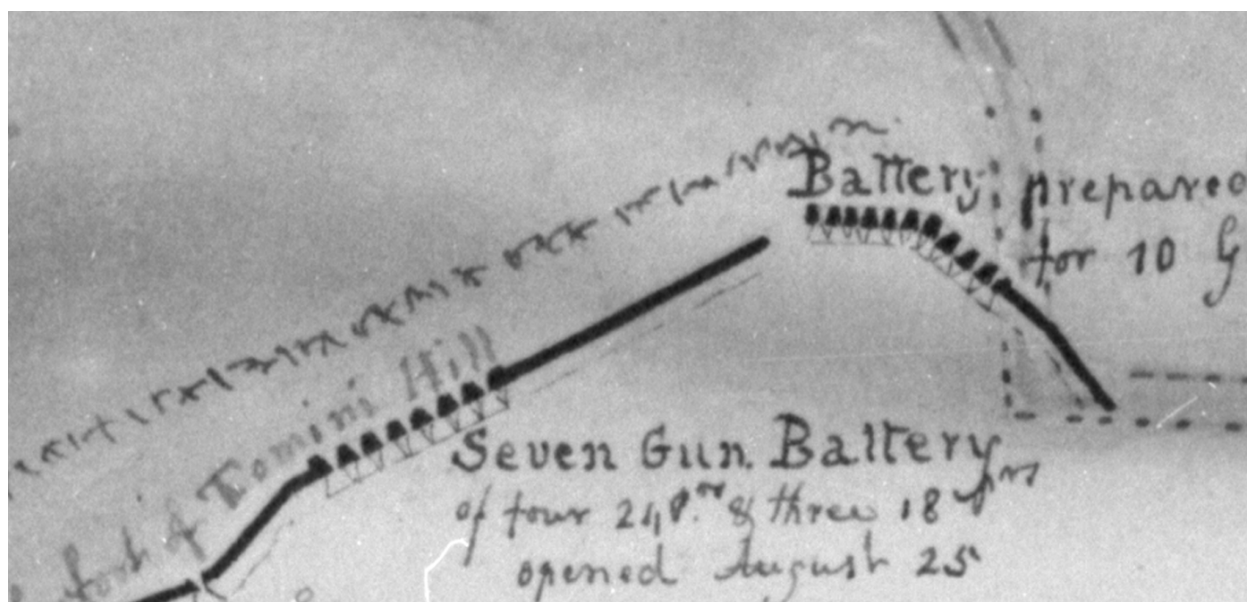


Figure 2.1 The 7- and 10-gun batteries at Green End, as seen on the 1778 Fage map.⁸⁷

⁸⁷ Fage, *Plan of the Works*, 1778. William L. Clements Library, University of Michigan.

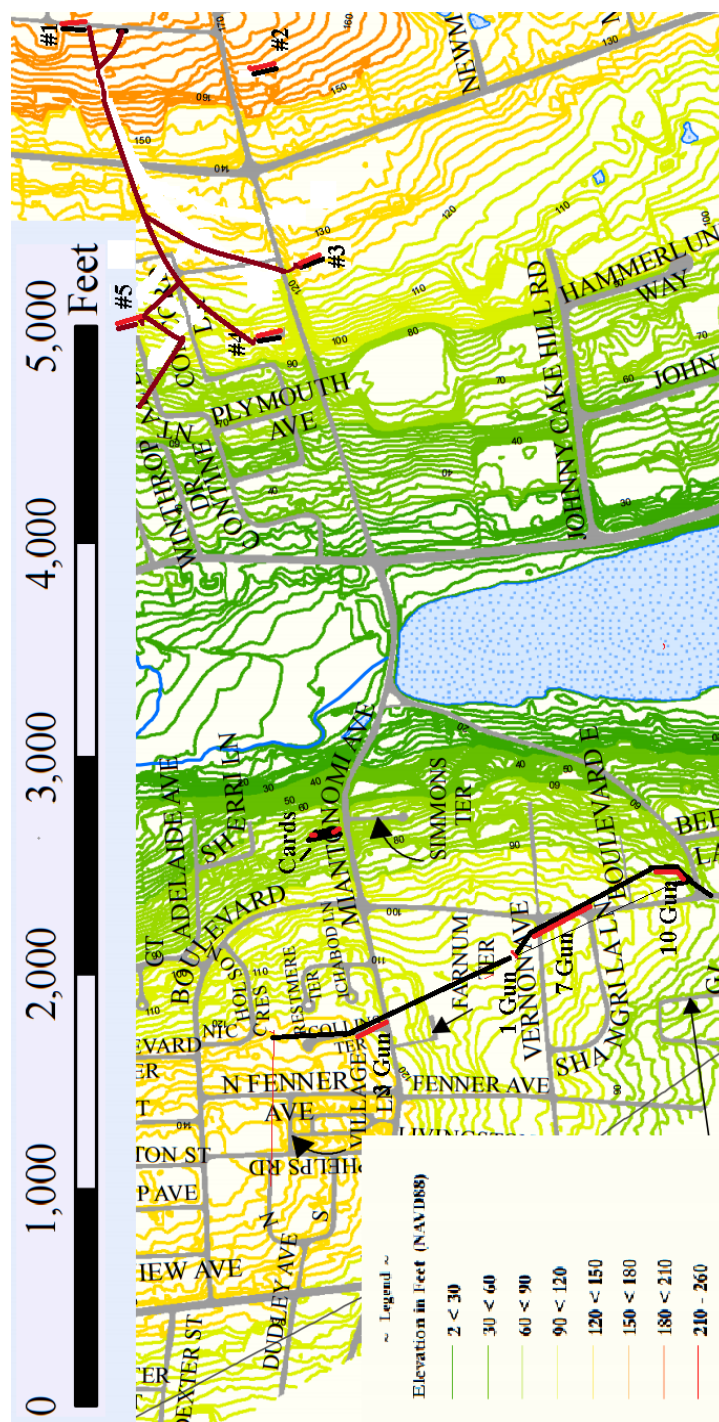


Figure 2.2 Location and elevation of British (left) and American (right) batteries and connecting trenches are seen marked in red on this topographic map. British positions at Card's Redoubt (70 ft.), the 10-gun battery (90 ft.), and the 7-gun battery (102 ft.) are the works to the left (west) of Easton's Pond. The American batteries, # 1 (178 feet), #2 (160 ft.), #3 (126 ft.), and #4 (108 ft.) and the trench works connecting them on Honeyman Hill are to the right (east) of the pond.⁸⁸

⁸⁸ *Elevation Map of Middletown, Rhode Island, Town of Middletown, 2015.*

2.1.2 Establishment of American Gun Batteries

Unlike the British, who were afforded the time to fortify in advance, the Americans developed their fortifications over the course of a week while conducting the Siege (Figure 2.2). Batteries 1 and 2 (Figure 2.3 A and C) were constructed on August 17 and 18, just before their operations in Middletown had been detected. By the 19th, both of these batteries were in working order and firing 18 pound guns at the British.⁸⁹ Despite their altitude advantage, the Americans were still out of effective range (roughly 2,000 yards out) and needed to work their way closer to the enemy lines. Over the following days, while ducking in and out of the trenches to avoid cannon fire, a series of new batteries and trench works were built, creeping down the western slope of Honeyman Hill (Figure 2.3). Batteries 3 and 4 (Figure 2.3, E and F) were constructed within 1,000 yards of the British front lines and were firing by August 23. Even at this closer range, the 18-pound cannon still failed to penetrate the six-foot-thick British revetment (Figure 2.4). Simulations and analytical models were assessed to understand why the British retained their revetment, and the details of these analyses are listed later in this chapter.

⁸⁹ *DFM*, 2: 361



Figure 2.3 American approach (top) down Honeyman Hill, toward British lines (bottom). The letters along the American trenches show various works. Batteries A and C were constructed first, soon followed by E and F.⁹⁰

⁹⁰ D'Aubant, *Plan of the town and environs of Newport, Rhode Island / Exhibiting its defenses*, 1779, William L. Clements Library, University of Michigan.

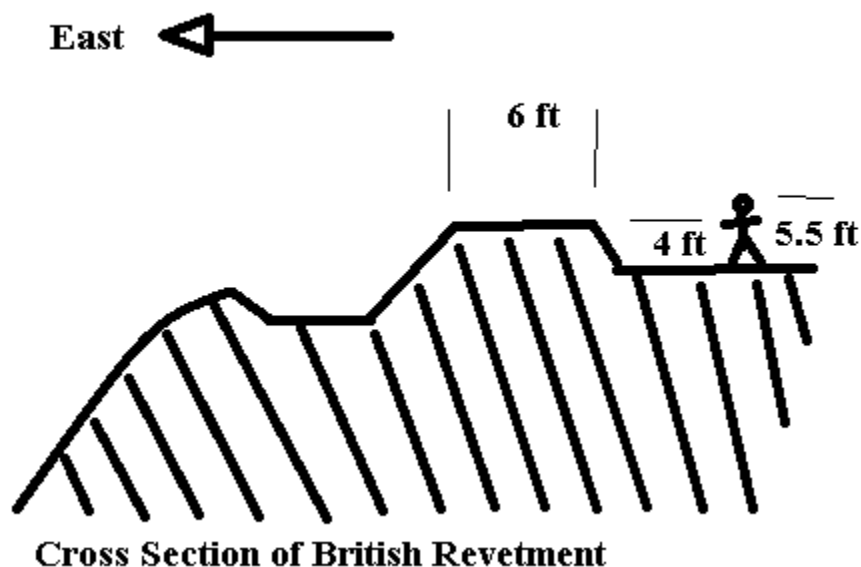


Figure 2.4 Cross section of the British revetments on Bliss Hill. Drawn by author using figures from Mackenzie's Diary.

2.1.3 British Fields of Fire

The British had at least 44 cannon set up across the outer line, from the 10-gun battery to Tonomy Hill. Figure 2.5 shows the distribution of this artillery, which included two 6-pound, two 8-pound, 28 12-pound, seven 18-pound, five 24-pound guns. These cannon were arranged in interlocking fields of fire that would have been effective against an attack by the American infantry across Bailey's Brook. Figure 2.6 illustrates this coverage and the field of fire the Americans would have faced if they had tried to storm across the swamped valley. The British guns had an effective range of 1,000 yards and a maximum range of roughly 2,000. Since the American batteries #3 and #4 were within 1,000 yards of the British line, Bailey's Brook was well within range, so the British interlocking fields of fire would have annihilated any force that tried to storm across.

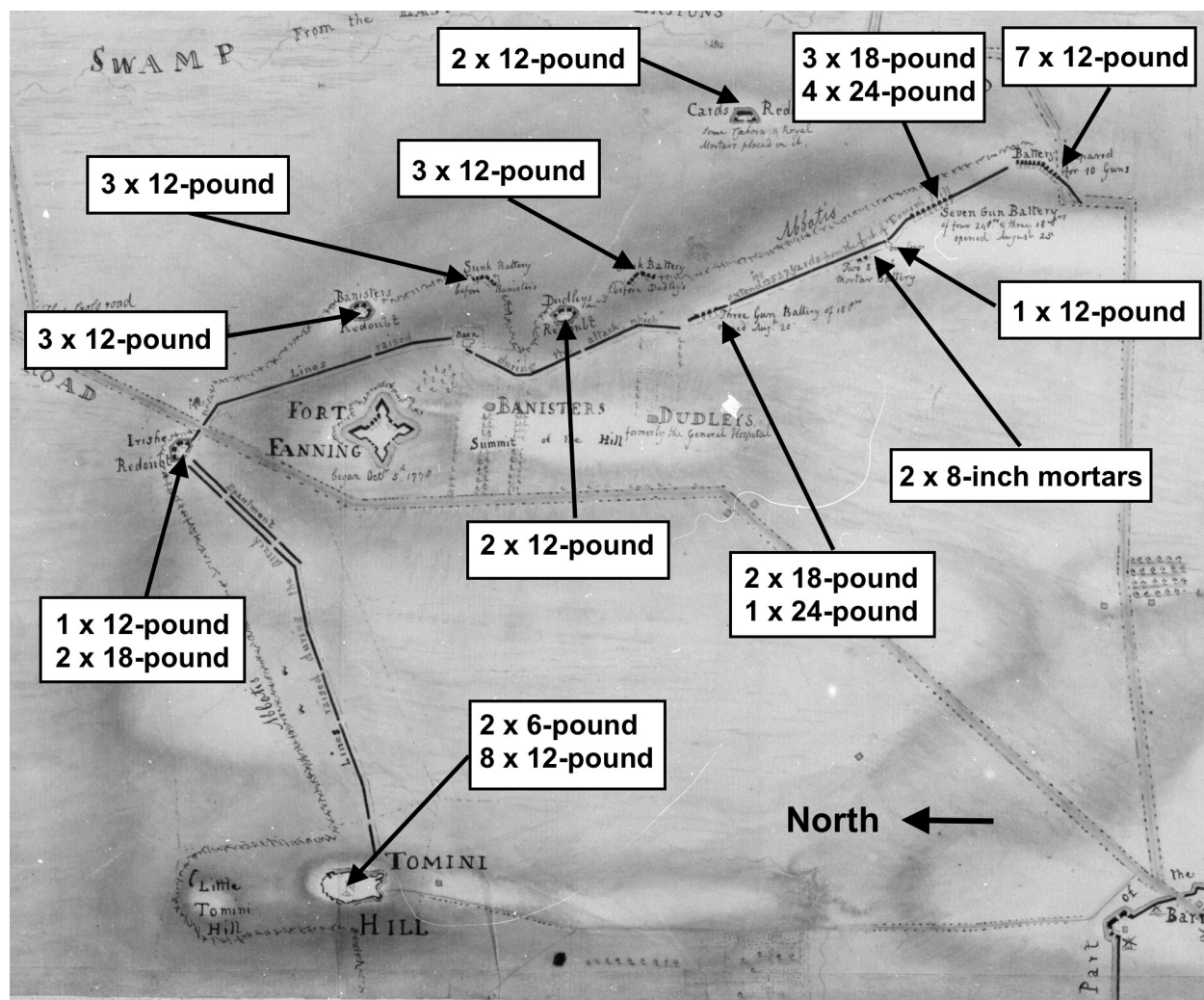


Figure 2.5 Cannons throughout the British front lines labeled on the 1778 Fage map.⁹¹

⁹¹ Fage, *Plan of the Works*, 1778. William L. Clements Library, University of Michigan.



Figure 2.6 British interlocking fields of fire. The cannon were effective at a range of roughly 1,000 yards.⁹²

⁹² D'Aubant, *Plan of the town and environs of Newport, Rhode Island / Exhibiting its defenses*, 1779, William L. Clements Library, University of Michigan.

To provide the coverage, the British redoubts were constructed with gun ports facing left, center, and right. Card's Redoubt was the one exception. Perched east of the connected batteries and redoubts that made up the British outer line, on the steep Green End area of Bliss Hill, its gun ports faced left and right only (north and south) (Figures 2.7). If the Americans did manage to get across the valley and attempt to scale Green End, the cannon at Card's Redoubt would have a clear shot to stop these assailants. Further, Card's right (southeast) port (Figure 2.6, green), covered the blind spot at the base of Green End Avenue.

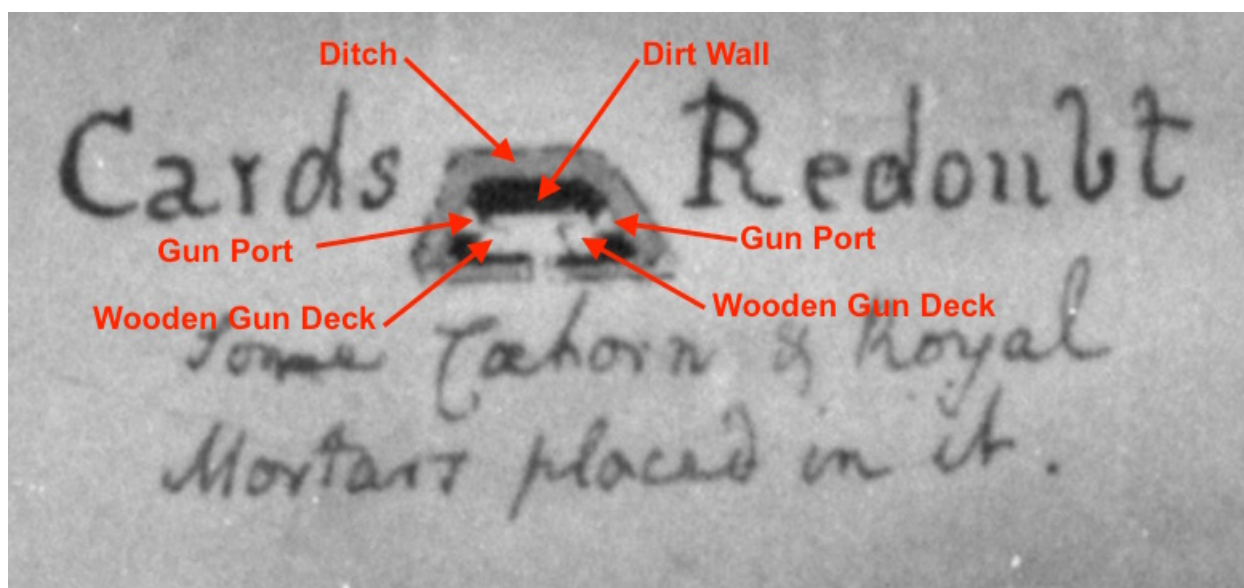


Figure 2.7 Card's Redoubt wooden gun decks and gun ports were about ± 30 degrees.⁹³

2.1.4 Elevation Considerations

The British were using 12-pound field guns mounted on carriages so that they would move smoothly back with the recoil. Both the British and American gun positions had wooden decks to allow the guns to move easily and to be aimed roughly ± 30 degrees from the direction

⁹³ Fage, *Plan of the works*, 1778. William L. Clements Library, University of Michigan.

of the axis of their gun port. The British had to elevate the cannon muzzle to 6 degrees to reach the American batteries at #1 and #2 but could not deliver accurate fire (elevation shown in Figure 2.2). A lower elevation was used against #3 and #4. In all cases the British cannons were ineffective against the American gun batteries. Likewise, the American 18-pound cannon (Figure 2.8, Figure 2.9 shows a 6-pound gun) continued firing on the British to no avail. The technical supplement provided in Appendix G asserts that properly adjusting the angle at which the cannon is fired for the desired position downfield is crucial for hitting a target. Inexperienced artillerymen or platform damage could cause a change in angle when firing, leading to improper angle adjustment. Analytical models were used to simulate the cannon fire for the geography at Honeyman Hill to reveal the exact nature of the inaccuracy caused by inexperience and damage, discussed in detail in the technical supplement located in Appendix G.

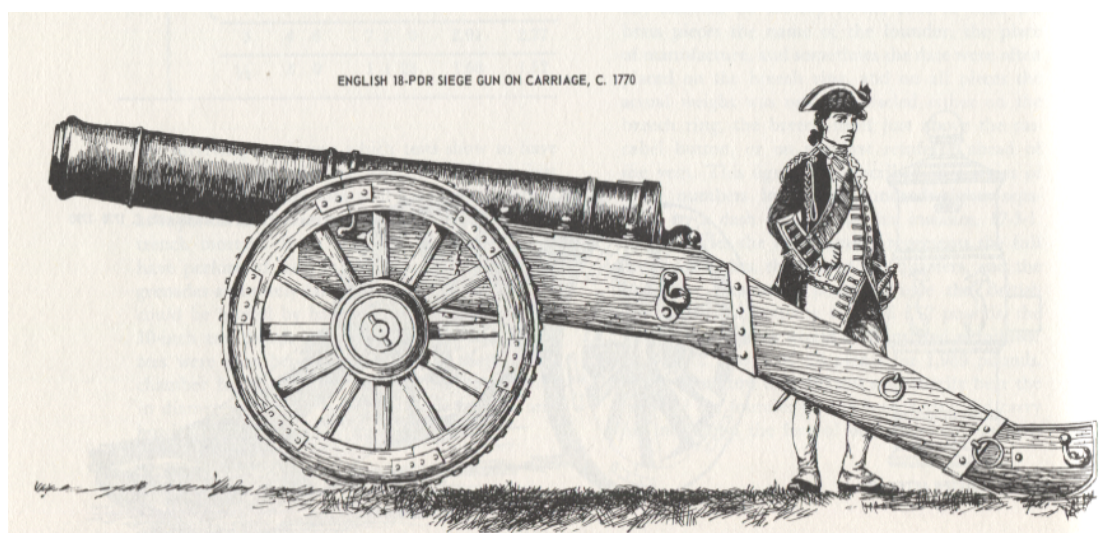


Figure 2.8 British 18-pound field guns.⁹⁴

⁹⁴ Peterson, 44.

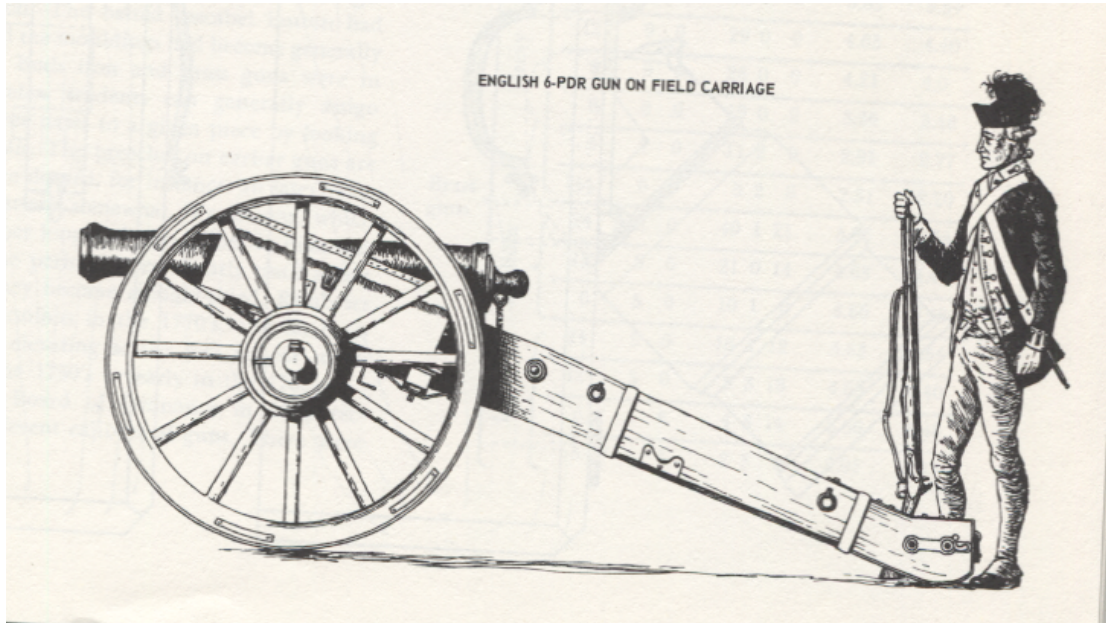


Figure 2.9 British 6-pound Field guns.⁹⁵

2.2 Cannon Analysis

The technical data used in this chapter pulls from a study and analysis on the artillery used by the Americans, including its range, trajectory, power, accuracy, and the ability to penetrate (or not) earthen fortifications. A full detailed technical report, including the MATLAB⁹⁶ simulation code and results, is available in Appendix G.

2.2.1 Analysis of Smooth Bore Cannon

Information pertaining to the performance of 18th century smooth bore cannons is very limited and mostly anecdotal. The first works on cannon ballistics were completed by Benjamin

⁹⁵ Peterson, 39.

⁹⁶ Engineering software produced by MathWorks in Cambridge, MA, used to solve engineering and scientific problems. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

Robins, an Engineer General to the East India Company.⁹⁷ Robins' work was revised and published by Dr. A.R. Collins.⁹⁸ This work, with minor corrections and adjustments, was used as the principal reference for MATLAB programming thus used to generate the figures for this report. A verification of the software came from the recovery of a 12-pound British cannonball (Figures 2.10 and 2.11) recovered from a garden on Turner Road in Middletown, RI.



Figure 2.10 A Middletown resident holds the cannonball he recovered from his Turner Road property (right). He has verified the location where it was found and has since donated the artifact to the Middletown Historical Society. It has since been identified as a 12-pound British cannonball that was likely fired at the American's positioned on Honeyman Hill (left). Photo by author.

⁹⁷ Benjamin Robins, *New Principles of Gunnery containing The determination of the Difference in the Force of Gunpowder and The resisting power of air to swift and slow motions*. 1750, Republished in 1805 with corrections by F. Wingrave in the Strand, London.

⁹⁸ <http://arc.id.au/Cannonballs.html> downloaded 2/21/2016 and <http://arc.id.au/CannonBallistics.html>



Figure 2.11: An American 18 lb. cannon ball recovered from Card's Redoubt and donated to the Middletown Historical Society. Photo by author.

This outcome provided confidence that the simulation, based on Robins and Collins, could be used to analyze the performance of other cannons used in the battle. Results of the simulation were also paired with a recovered cannonball fired from Bannister's Redoubt mentioned in the diary. Figure 2.12 shows a recovery distance of 1,890 yards. The simulation shows that firing at about 5.5 degrees would result in a travel distance of about that length (Figure 2.13).

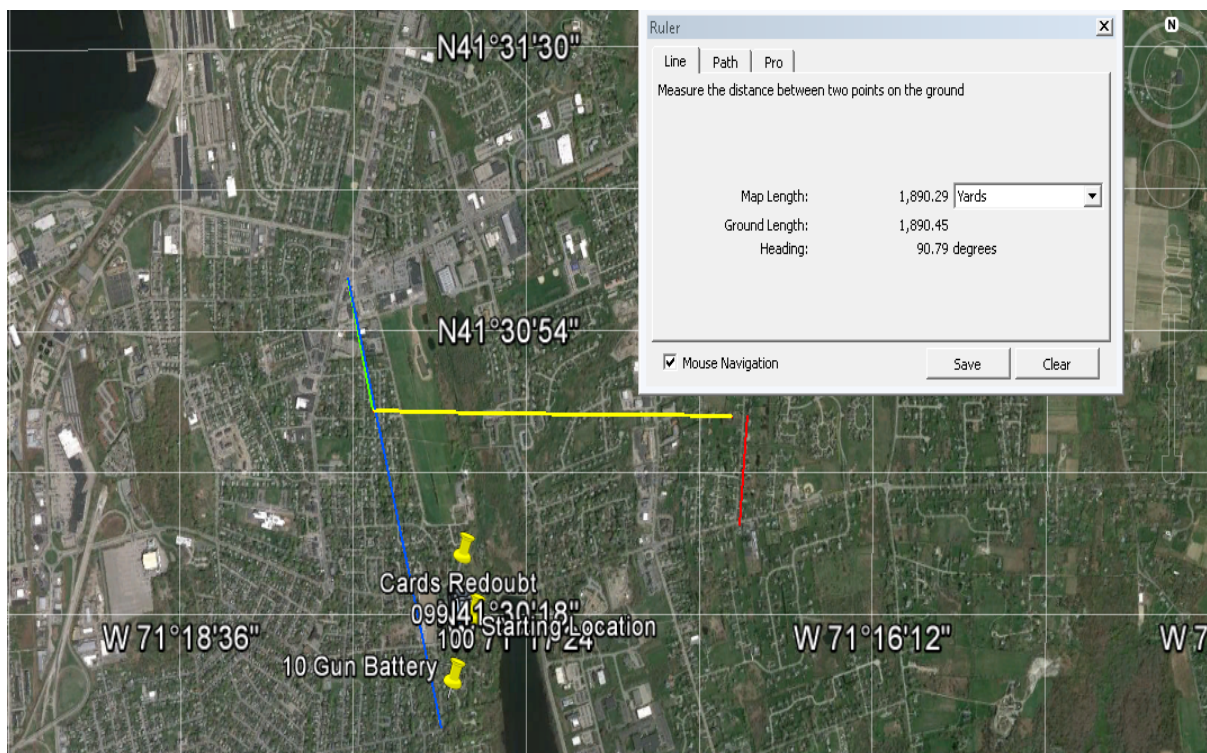


Figure 2.12 The distance from Banister's Redoubt to the recovery location is 1,890 yards.⁹⁹

⁹⁹ As measured by Google Maps (Yellow line)

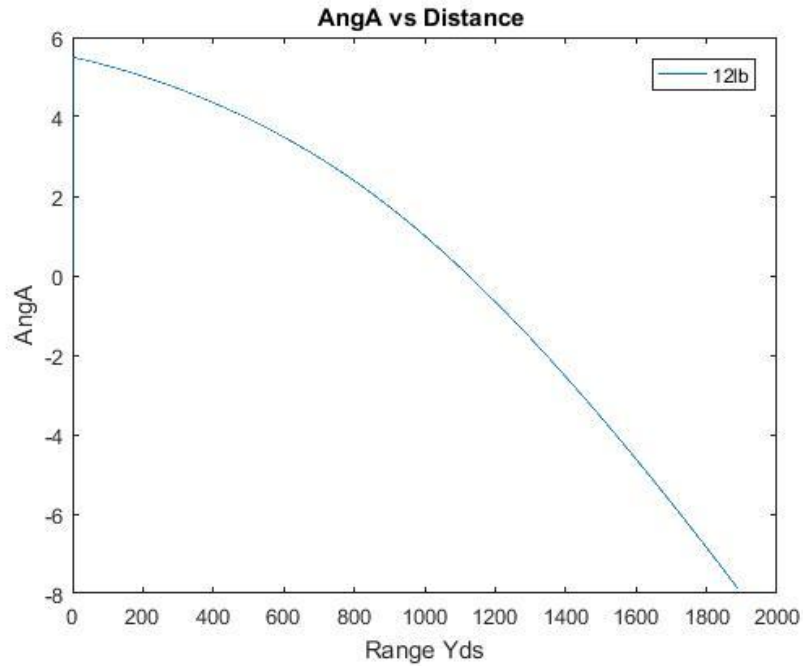


Figure 2.13 Angle of attack of a 12-pound cannonball over travel distance. Initial angle of attack was 5.5 degrees. The cannonball impacted the farmland at an angle of -8 degrees.

Figure 2.14 shows tabulated results from the MATLAB simulation beyond just the angle of attack. These results were used to assess variability in ballistics for cannonballs of varying mass and initial parameters, such as gunpowder quality and firing angle, as well as penetration of the cannonball into fortifications.

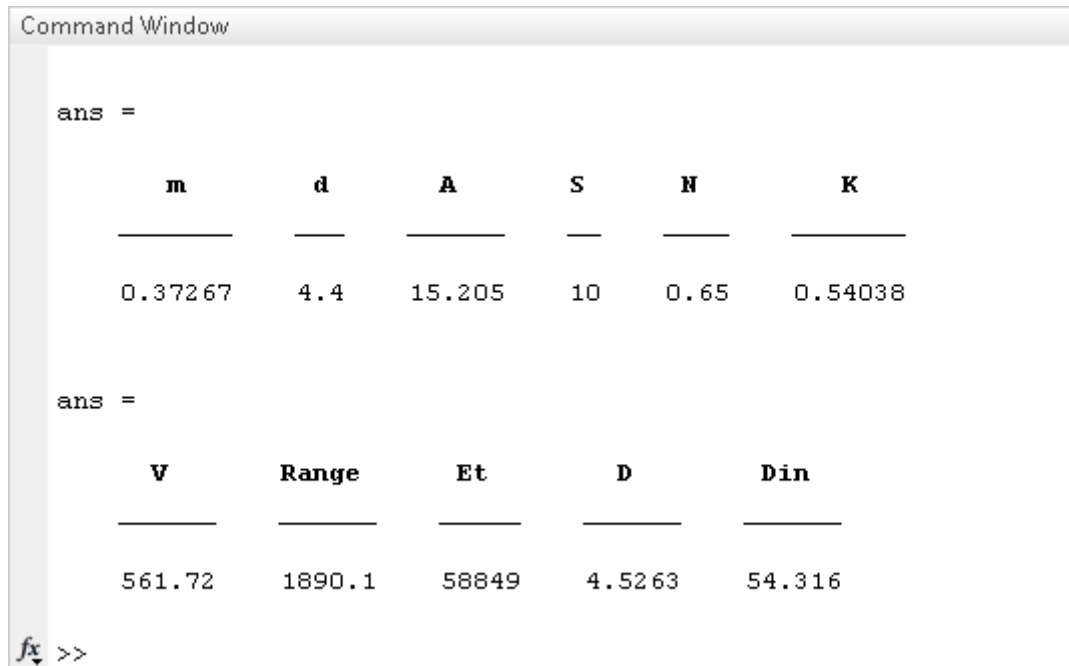


Figure 2.14 Tabulated results from MATLAB simulation for a 12-pound cannonball. Results shown include mass, diameter, area, soil index, % tangent ogives nose performance, % soft soil for weight < 60 pounds, velocity, range, total kinetic energy, penetration of soil in feet, and penetration of soil in inches.

Figures 2.15 through 2.17 show the MACH number, velocity, and Reynolds number¹⁰⁰ versus distance for the 12-pound cannonball.

¹⁰⁰ A dimensionless number that gives a measure of the ratio of inertial forces to viscous forces for given flow conditions. The Reynolds number is an important parameter that describes whether flow conditions lead to laminar or turbulent flow.

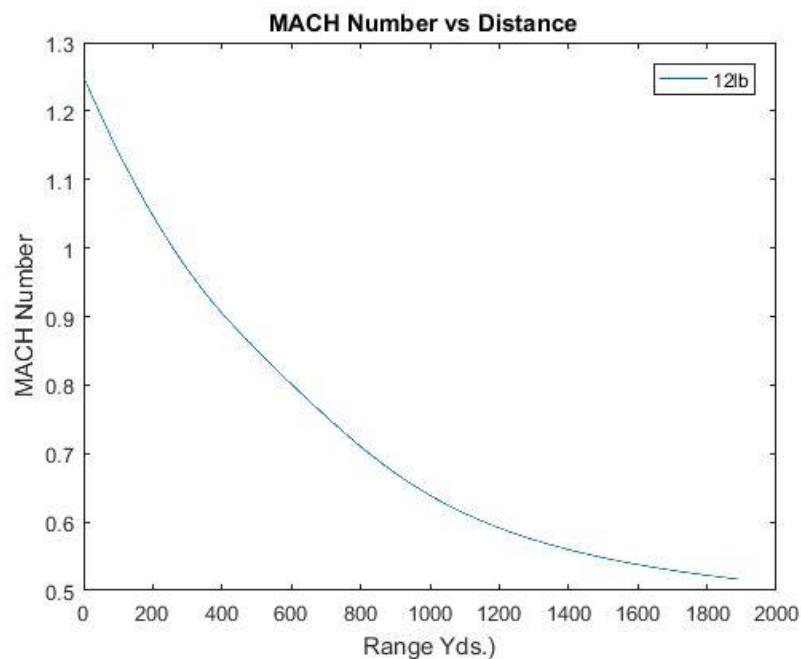


Figure 2.15 MACH number of a 12-pound cannonball versus distance traveled post firing. The cannonball exits the muzzle at a velocity of 1,359 feet per second. That is a speed of MACH 1.26.

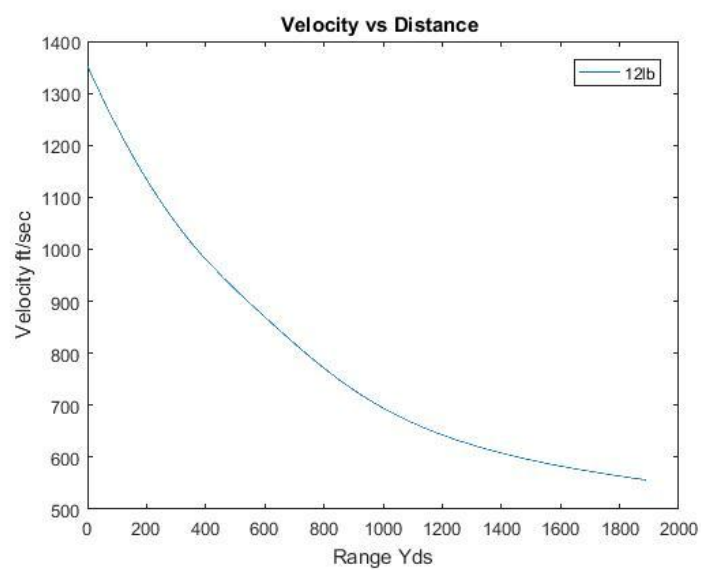


Figure 2.16 Velocity of a 12-pound cannonball versus distance traveled. The terminal velocity was about 560 ft./sec.

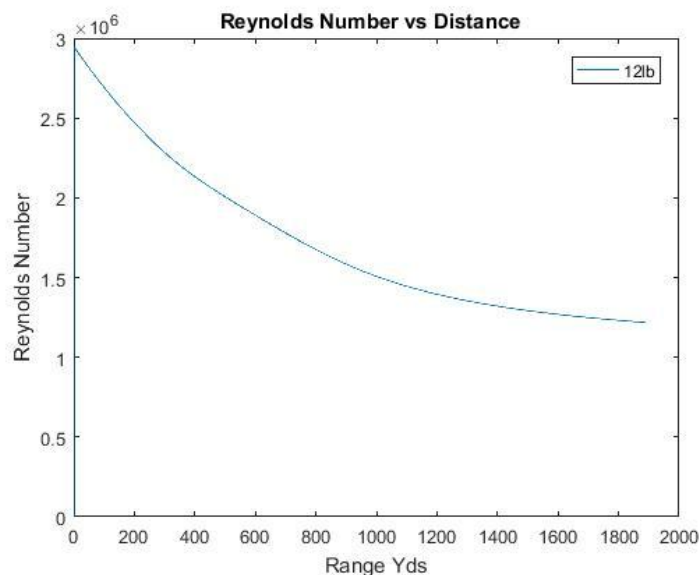


Figure 2.17 Reynolds Number of a 12-pound cannonball in flight versus distance traveled. Note that the Reynolds number is within the turbulent range throughout its flight. More detail found in the technical supplement.

2.2.2 Penetration and Range

The American cannons had to be able to disable the British artillery that were riveted on the west side of the valley. To do this, the cannons would have to send a ball with enough energy to penetrate six feet of dirt and have enough energy left to damage the British guns and crews beyond the revetment. Figure 2.18 shows a cannonball penetrating into a revetment with insufficient energy to break through the fortification. Alternatively, cannon fire would have to repeatedly target the same area on the revetment¹⁰¹ as to cumulatively administer enough damage to break through the defenses.

¹⁰¹ A barricade of earth or sandbags set up to provide protection from blast, protecting a rampart, wall, etc.

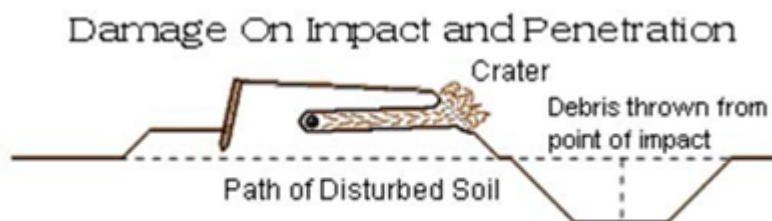


Figure 2.18 Image of cannonball penetrating revetment. Insufficient penetration depth can be seen in the image.¹⁰²

Penetration data for field guns of various sizes can be seen in figure 2.19, while common cannonball sizes can be seen in figure 2.20.

Penetration in Compact Earth, (half sand, half clay.)									
CALIBRE.	CHARGE.	DISTANCE IN YARDS.							
		27	55	109	219	328	438	656	875
Guns,		In.	In.	In.	In.	In.	In.	In.	In.
36	1-3d	109.1	106.3	102.4	97.3	93.4	89.4	82.3	75.6
	1-2nd	108.2	107.2	99.3	91.0	84.3	79.6	72.5	66.2
	1-3d	100.4	97.7	92.6	85.9	81.1	77.2	70.1	63.4
24	1-4th	92.6	90.2	86.6	81.5	77.6	74.0	67.3	61.8
	1-6th	83.5	82.3	79.9	75.6	72.2	68.9	62.6	57.1
	1-8th	76.4	74.6	72.4	68.9	65.8	63.0	57.5	52.0
16	1-2nd	94.5	91.0	85.9	77.6	72.2	67.7	61.4	55.9
	1-3d	86.6	83.5	79.6	73.6	69.3	65.8	59.9	54.4
	1-4th	80.7	78.3	75.2	69.7	66.5	63.4	57.9	52.4
12	1-6th	72.9	70.9	68.1	65.0	61.8	59.1	53.6	48.8
	1-8th	63.0	65.4	63.8	60.6	57.9	55.1	50.4	45.7
	1-3d	65.0	63.4	59.9	54.7	50.8	48.2	42.9	38.6
8	1-4th	60.6	59.1	55.9	52.0	48.8	46.1	41.3	37.4
	1-6th	54.7	53.6	50.8	48.2	45.3	42.9	38.6	35.0
	1-8th	50.0	48.8	47.3	44.5	41.7	39.8	36.2	33.1
8	1-3d	56.3	54.7	52.0	46.9	43.3	40.2	35.4	31.9

Figure 2.19 Penetration data from a French study¹⁰³ used by the United States Army. Note the sizes are on the French Valliere system.¹⁰⁴

¹⁰² Dictionary of Fortification: Penetration, Solid Shot. Civil War Fortification Digital Research Library. Web. (<http://lly.org/~rcw/cwf/dictionary/xgp-015.html>), 2004.

¹⁰³ As referenced in Dictionary of Fortification: Penetration, Solid Shot.

¹⁰⁴ Dictionary of Fortification: Penetration, Solid Shot, Web.

Weight and Diameter of Solid Shot

6-pdr	3.58" 6.10 lbs.
12-pdr	4.52" 12.30 lbs.
18-pdr	5.17" 18.50 lbs.
24-pdr	5.68" 24.40 lbs.
32-pdr	6.25" 32.60 lbs.

Figure 2.20 Standard shot sizes for British artillery¹⁰⁵

Note that the shot sizes in the penetration table do not match the British standard sizes. In fact, the data was generated by the French. There was initial doubt as to the accuracy of the data in Figure 2.19 and some way needed to be found to verify it.

In 1997 Sandia National Laboratories funded a study to define the equations necessary to determine the best way to penetrate the various forms of bunkers.¹⁰⁶ The equations were used by Dr. Aaron Bradshaw to check the data in Figure 2.19. He produced a MATLAB script to predict the penetration capability of the American cannon. Results from the simulation found in his script can be seen in figures 2.21 and 2.22. "S" in these figures refers the penetrability of the soil. Dr. Aaron Bradshaw denotes an index between 8 and 10 as being soil fill material. The degree to which the soil is compacted causes the index to range between 8 and 10.

¹⁰⁵ *Dictionary of Fortification: Penetration, Solid Shot*, Web.

¹⁰⁶ C. W. Young *Penetration Equations* SAND97-2426, October 1997.

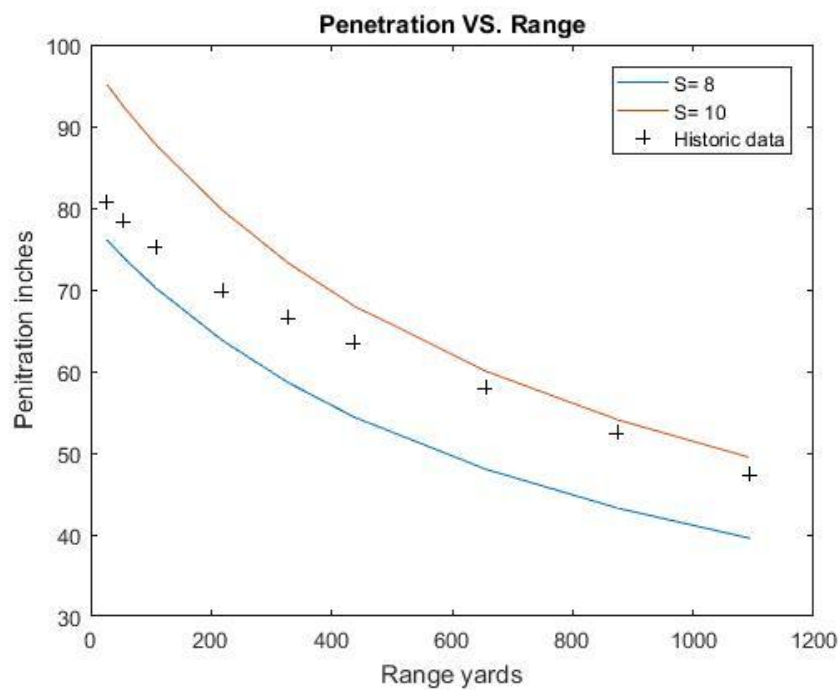


Figure 2.21 Penetration as a function of range for various degrees of soil compaction, S . Note that the historic data is also plotted in the figure for comparison.

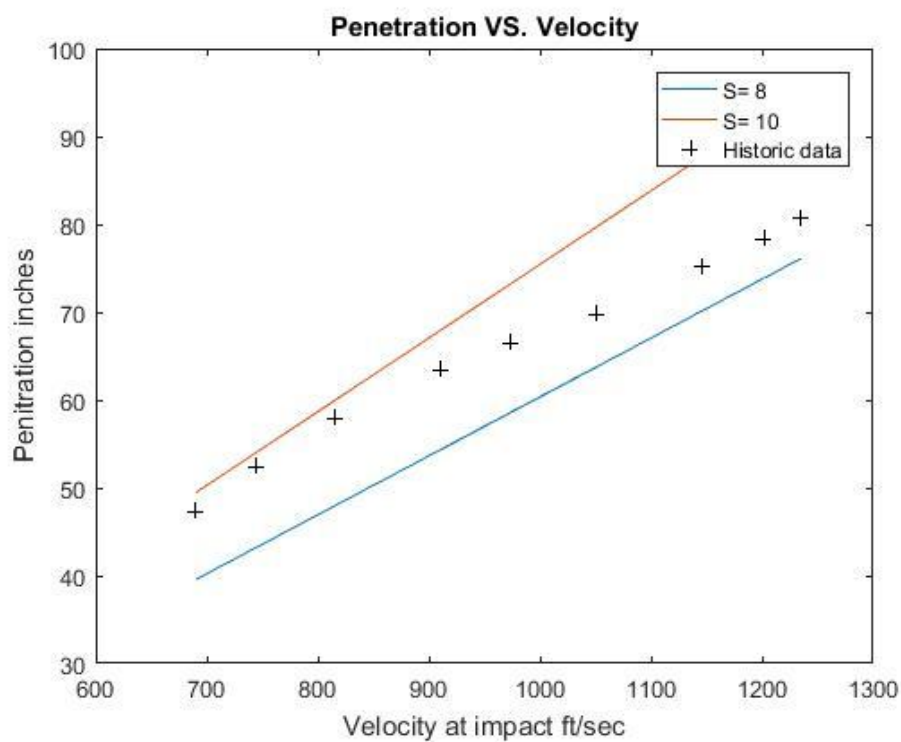


Figure 2.22 Penetrations as a function of impact velocity for various degrees of soil compaction, S . Note that the historic data is also plotted in this figure for comparison.

The historic data falls between the soil conditions shown in figures 2.21 and 2.22, indicating agreement between the empirical data from 1750 and the empirical data from Sandia Laboratory in 1997. Figure 2.22 displays a proportional relationship between impact velocity and depth of penetration; a roughly linear relationship. Therefore, a higher impact velocity is needed to penetrate farther into the revetment.

Table 2.1 shows the range between the different batteries and the British positions for reference when approximating penetration.

Table 2.1 Ranges (kilo yards) from the American batteries to the British positions.¹⁰⁷

Battery	Card's Redoubt	7-Gun Battery	10-Gun Battery
#1	1.29	1.6	1.526
#2	1.23	1.375	1.305
#3	0.92	1.03	0.97
#4	0.7625	0.95	0.92

From Figure 2.19, the range at which an eighteen-pound cannonball would penetrate six feet of dirt (72 inches) would be 50 yards for a soil compaction index of 8, and 300 yards for a soil compaction index of 10. The American cannon, even when fired from the most forward batteries (#4 to Cards Redoubt, #3 to Cards Redoubt, and #4 to 10 Gun Battery) are not close enough to the enemy revetments to achieve the necessary penetration of six feet to break through to the artillery.

¹⁰⁷ Fage, *Plan of the works*, 1778. William L. Clements Library, University of Michigan.; Based the map and its distance scales.

The French fleet abided by a 1732 ordinance, which standardized French cannons as 24-, 16-, 12-, 8-, and 4-pounders. The 24-pounder had a 5-2/3 inch bore, a 9-foot 6-inch long barrel, and weighed 5,400 pounds. Admiral d’Estaing’s warships carried 24-pound and 36-pound cannon. Table 2.2 below shows the quantity of guns Admiral d’Estaing carried on his warships.

Table 2.2 Guns aboard d’Estaing’s *Languedoc*, *Tonnant* and *Cesar*.¹⁰⁸

Ship	Guns	Draft	Number and Type of Gun
<i>Languedoc</i>	80	25	30 x 36-pound, 32 x 24-pound, 18 x 8-pound
<i>Tonnant</i>	80	25	
<i>Cesar</i>	74	22	28 x 30-pound, 30 x 18-pound, 18 x 8-pound

If the French 36-pound or 24-pound cannon could have been made available from the *Languedoc* and used from Honeyman Hill positions #3 and #4, the damage to the British artillery would have been increased. For the most compact soil (8) a:

36-pound cannon in Battery #4 would penetrate Card’s Redoubt to 92.95 inches

36-pound cannon in Battery #4 would penetrate 7-gun Battery to 83.8 inches.

24-pound in Battery #4 would penetrate Cards redoubt to 62 inches

24-pound gun in Battery #4 would penetrate 7-gun Battery to 60.9 inches

From this analysis, it can be concluded that the 24-pound gun would have been effective at penetrating the defenses. The British hauled water to their earthworks to wet them down and maintain their stopping power. To be effective against the British defenses that were 72 inches thick, the Americans would need 36-pound cannon in the advanced gun batteries (#3, #4).

¹⁰⁸ Hattendorf, 5-8

Table 2.3 below shows the various altitudes and effective ranges for the different batteries, forts and guns in the battles.

Table 2.3 Range of the American batteries to their British targets, with the altitude of each position listed in parenthesis following its name.¹⁰⁹

Batteries	Card's Redoubt (70 ft.)	7-Gun Battery (112 ft.)	10-Gun Battery (88 ft.)
#1 (176 ft.)	1.288 kyd.	1.527 kyd.	1.583 kyd.
#2 (158 ft.)	1.778 kyd.	1.381 kyd.	1.381 kyd. (1.350)
#3 (132 ft.)	0.891 kyd. (980) ¹¹⁰	1.094 kyd.	1.091 kyd. (960)
#4 (124 ft.)	0.760 kyd. (780)	1.005 kyd.	1.032 kyd (1150)
#5 (120 ft.)	0.847 kyd.	1.111 kyd.	1.15 kyd.

2.2.3 Cannon Ball Placement Errors

There are a number of considerations that will influence the deviation of the cannonball in flight, preventing it from accurately hitting a target. The cannons were mounted on a gun carriage above the center of gravity of the combined structure, causing the firing of the cannon to impart a torque on the cannon and carriage. The wheels of the gun carriage may not have the same starting torque when the cannon is fired and it may change with time, causing the cannon or structure to move after the resultant impulse from firing. Furthermore, this torque and impulse may damage the carriage over time, leading to sway of the muzzle when firing, which would lead to inaccurate aiming of the cannon. The gunner sighting the cannon may also introduce both

¹⁰⁹ Fage, *Plan of the works*, 1778. William L. Clements Library, University of Michigan; *Elevation Map of Middletown, Rhode Island*; Calculated distances as measured in Google Earth.

¹¹⁰ Based on *DFM 2*: 385, values for Batteries 3 and 4 were interchanged. See red text.

azimuth¹¹¹ and elevation errors (Figure 2.23). Additionally, variations in gunpowder quality due to moisture, manufacturing or other sources would cause variations in landing positions which could lead to inaccuracy. Finally, if the ball makes contact with the barrel, there may be a spin introduced that will cause the ball to take a curved trajectory. At low angles the effect is minimum. A sensitivity analysis was completed and recorded in the technical supplement found in Appendix G for each case mentioned above, as well as other parameters such as the presence of a cross-wind. This analysis was used to determine which elements of firing a cannon when varied would result in the most significant changes in ballistics.

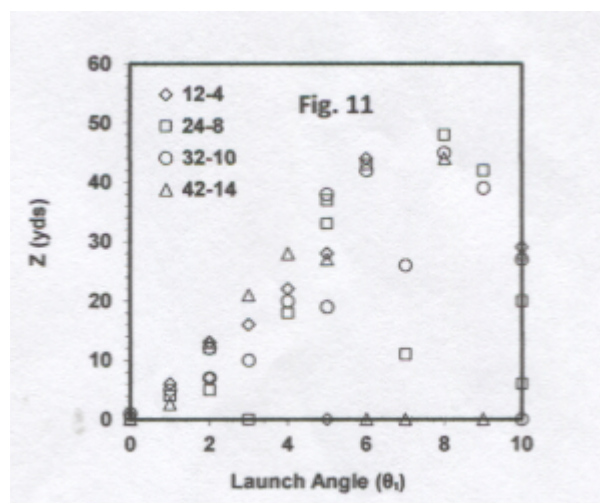


Figure 2.23 Deviation as a function of elevation angle.¹¹²

¹¹¹ The angle of horizontal deviation, measured clockwise, of a bearing from a standard direction, as from north or south.

¹¹² Stephen A. Jordon, *Trajectory of a Cannonball*, located in Appendix G.

Below are various analytically-derived errors for the geometry of Cards Redoubt (Figure 2.24), as well as results from the MATLAB sensitivity analysis.

Sighting errors are:

0.5 deg. = 8.73 yards at 1000 yards	0.79 inch off center at muzzle
1 deg. = 17.45 yards	1.58 inch off center at muzzle
2 deg. = 35.00 yards	3.17 inch off center at muzzle

Elevation angle errors produce the largest range errors:

0.8 deg = 904 yards (Delta of -95 yards)
0.9 deg = 936 yards (Delta of - 63 yards)
1.0 deg = 967 yards (Delta of - 32 yards)
1.1 deg = 999.23 yards (Delta = 0)
1.2 deg = 1030 yards (Delta of 31 yards)
1.3 deg = 1061 yards (Delta of 62 yards)
1.4 deg = 1092 yards (Delta of 93 yards)

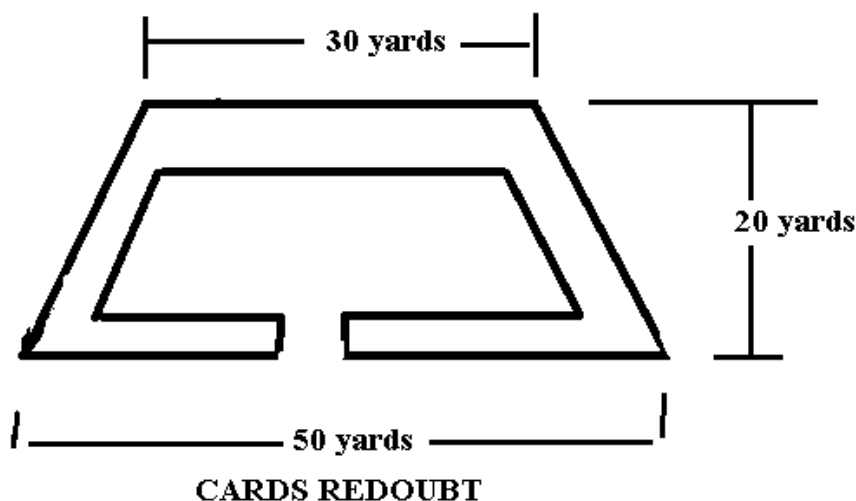


Figure 2.24 Dimensions of Cards Redoubt, based on the 1778 Fage map.¹¹³

If one standard deviation (SD) of the aiming error is 0.5 degrees then the redoubt would subtend ± 4 SD of the cross range error. If the standard deviation of the vertical angle is 1.26 degrees there will be 10% hits on the redoubt, which is what Mackenzie noted in his diary.

2.2.4 Technical Conclusions

Given their position, distance from and depth of the British earthen works, artillery available, and aiming errors, the Americans' 18-pound cannon were not powerful enough to penetrate the enemy fortifications, and also likely to miss due to the number of impactful parameters (elevation, gunpowder quality, carriage damage, etc. More detail in the technical supplement) on cannonball trajectory, as well as the sensitivity of that trajectory to those parameters. If they had more substantial artillery, such as the 24-pound or preferably the 36-pound guns on d'Estaing's *Languedoc*, the Americans could possibly have disabled Card's Redoubt and the 7 and 10 gun batteries and changed the outcome of the battle.

¹¹³ Fage, *Plan of the works*, 1778. William L. Clements Library, University of Michigan.