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Deviation Effect of an In-Bore Centerline on a 5-Inch Naval Gun

by Thomas F. Erline

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Deviation Effect of an In-Bore Centerline on a 5-Inch Naval Gun

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Abstract

A naval cannon was analyzed with the Little RASCAL gun dynamics program to predict shot exit conditions. There appeared to be a sharp manufacturing bend in the barrel's vertical plane. The Little RASCAL program makes modeling many hypothetical cases easy. This report compares the projectile and barrel interacting forces with and without the effects of the sharp bend. More importantly, a small sinusoidal variation in the deviation of the barrel centerline preceding the sharp bend presents itself as a detrimental factor by amplifying the lateral forces.

Acknowledgments

The author appreciates the efforts of R. Bowen and R. D. Cooper of Naval Surface Warfare Center Dahlgren Division (NSWCDD) for contacting the U.S. Army Research Laboratory (ARL) to conduct this work. Also, many thanks are extended to T. Marrs and D. Swan of the U.S. Army Aberdeen Test Center (ATC) for performing the centerline measurements at Dahlgren, VA. Last, but not least, Leo L. Fischer of the United Defense Limited Partnership (UDLP) helped this author many times by sharing his expertise of naval weapons.

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1. Introduction

This report considers a number of hypothetical cases where the centerline of a gun barrel changes from a bent state to an unbent state. All other parameters remain the same. In the process of analyzing these hypothetical cases, a concern came up as to why the maximum value of the lateral forces was not significantly changed. It was found that a small sinusoidal variation in the deviation of the centerline of the barrel initiates a projectile rocking frequency that produces higher oscillatory lateral forces. This study can be considered a simple functional analysis. All variables are held constant except for the centerline (the domain). The Little RASCAL gun dynamics code [1] is used as the operator to give the resultant barrel-projectile interaction forces (the range). It is interesting to note that a small sinusoidal wave in a centerline drives lateral forces more than a single bend in a centerline. This finding is subject to the limitations of the assumptions within the Little RASCAL code.

The basis of the analysis starts with the simulated firing of the Mk64 projectile from the U.S. Navy's new 5-inch 62-cal. gun mount, the EX45 Mod4 [2]. A prototype 62-cal. barrel (serial number 17448) was mated to the EX45 Mod4 gun mount and was recently range tested. The U.S. Army Research Laboratory (ARL) Little RASCAL gun and projectile dynamics simulation program was used to model this gun system's lateral dynamics and provide the shot exit conditions when fired at service charge. This work was sponsored by the Naval Surface Warfare Center Dahlgren Division (NSWCDD) [3] as part of the Naval Surface Fire Support (NSFS) program.

2. Background

The objectives of the NSFS program require that 5-inch naval guns provide fire support from greater off-shore distances and hit targets with increased lethality. The key elements satisfying these objectives are an upgrade to the existing 5-inch 54-cal. Mk45 Mod2 gun mount and the development of the rocket-assisted projectiles (RAP).

NSFS modifications to the Mk45 gun system include structural enhancements to increase the allowable chamber pressure and ballistic impulse, replacement of the 54-cal. barrel with a 62-cal. barrel, and development of an adaptive digital control system that supports a new Gun Computing System (GCS) and RAP interface requirements. These modifications, plus development of certain RAPs, will allow the gun system to support engagement ranges of up to 63 nautical miles for certain RAP rounds and up to 21 nautical miles with future ballistic projectiles. Figure 1 illustrates the components of the EX45 Mod4 gun mount.

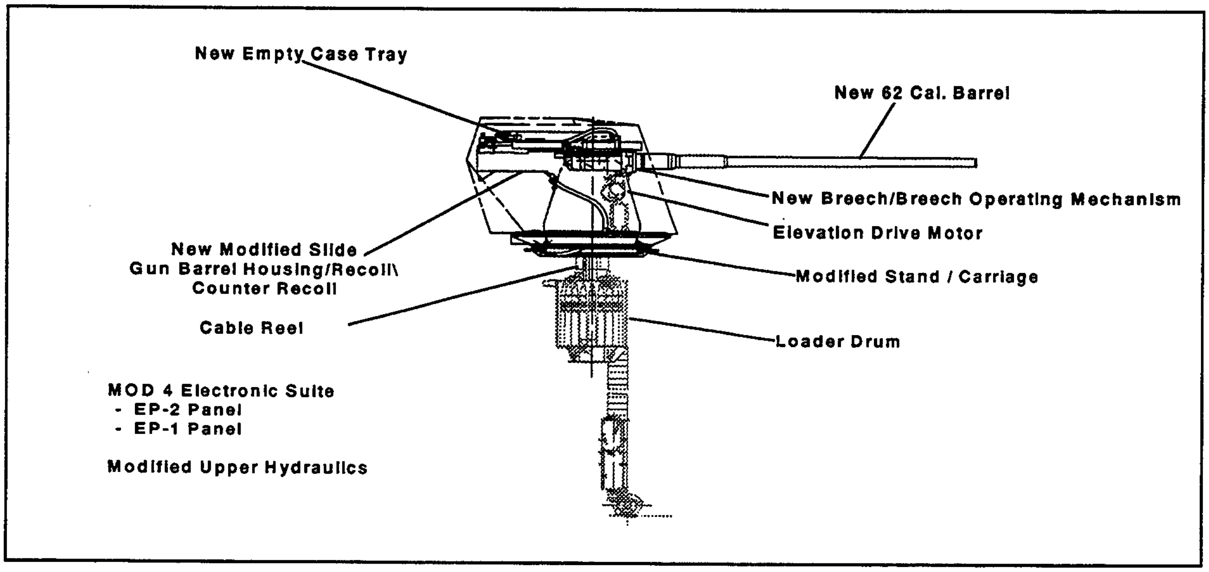

Figure 1. The EX45 Mod4 Gun Mount.

The 5-inch 62-cal. EX45 Mod4 gun mount is being developed for the U.S. Navy by the Armament Systems Division of United Defense Limited Partnership (UDLP). The original work supports a recent firing test at NSWCDD, Dahlgren, VA.

3. Approach

The Little RASCAL gun and projectile dynamics program was chosen for this effort because it can produce projectile exit conditions in a timely manner. Gun dynamics predictions of barrel motion made by Little RASCAL agree quite well with experimental results over a wide range of gun system sizes and types [4].

In addition, the 5-inch 54-cal. Mk45 Mod2 had been previously modeled [5] using the Little RASCAL code, and only minor changes to the gun mount and gun barrel data were required to accurately model the Mod4 gun mount. The gun system information input required includes the geometry and mass description of the gun barrel and breech along with breech center-of-gravity (CG) offsets, trunnion and elevation support locations, and their equivalent spring constants. Information concerning the dimensional mass properties of the 5-inch 62-cal. gun barrel, along with the information necessary to describe the Mod4 gun mount configuration, was supplied by UDLP [2].

The final gun system data requirement is a description of the variations in the gun barrel centerline. (The standard centerline definition is the deviation of bore center off of a straight line, starting at the center of the forcing cone and directed to the center of the muzzle. Recently, Army ballisticians have been reorienting the centerline axis, such that the support positions used at measurement time define the straight line axis. This configuration shows the wanderings of the centerline after the support up to the muzzle.) The centerline of the prototype 62-cal. barrel, S/N17448, displayed in Figure 2, was supported at 4,800 mm and 7,000 mm from the muzzle and was measured by the U.S. Army Aberdeen Test Center (ATC) personnel at Dahlgren, VA [5]. Only the vertical component of the centerline is displayed because this is the plane where the perceived hard-pressed bend is evident. In Figure 2, the solid line indicates the vertical centerline (CL) without gravity droop, the dashed line shows the CL with droop, and the line with "x" symbols shows the simple droop from the indicated supports.

4. Modeling

The Little RASCAL gun and projectile dynamics program is a dynamic displacement code employing a direct structural dynamics analysis approach to the simulation of firing a

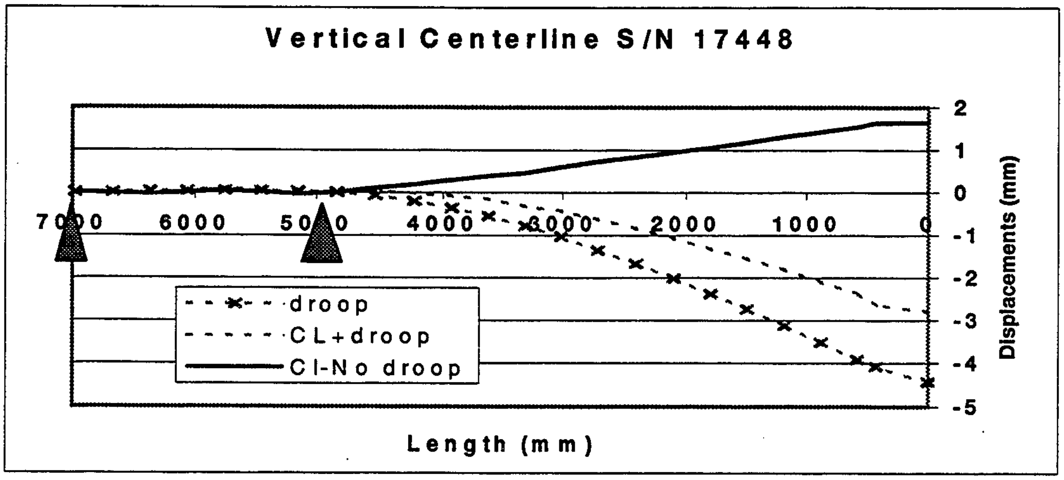

Figure 2. The Prototype 5-Inch 62-cal. Barrel S/N 17448 Vertical Centerline.

projectile from a gun. The program is capable of simulating the inertial loading conditions brought about by the projectile interacting with the barrel in a plane as it accelerates the length of the gun tube. The tracking of the inertial loading in-bore allows the program to predict initial launch conditions of the projectile at shot exit. In addition, projectile and gun flexural response can be observed.

Both the gun system and the projectile are modeled using a series of equally spaced cylindrical elements. The element nodes are centered and assigned equivalent mass and stiffness values that are based on standard engineering formulas. Inertial forces and flexural forces are calculated for this simplified description. Flexure at each node is approximated using a second-order finite difference method that also computes the bending forces. Transverse nodal accelerations caused by these forces are integrated once with respect to time to obtain transverse nodal velocities and again to obtain lateral node displacements. Loads induced by pressure effects, mounting conditions, breech CG offset, and the projectile's interaction with the barrel forces are taken into account. This algorithm does not emulate true balloting as the projectile is modeled in the bore without gaps and is forced to follow the dynamically changing centerline. Finally, the barrel is considered smoothbore.

The gun system (which includes the breech, barrel, and two gun supports) and the projectile system are two separate models. They are accounted for individually as finite structural systems, except for a variational algorithm that handles their interaction. The interaction of the projectile with the barrel occurs through contact points. The two contact points defined on the projectile are usually positioned where they occur geometrically. The two projectile contact point positions on the barrel are dynamic and change as the projectile traverses the bore. The gun system model and the projectile model are two separate, flexible entities, with each projectile contact point requiring a user-supplied spring constant. The spring constants serve to define the interface loads between the projectile model and the gun model. There is an algorithm within the program that adjusts the time step to ensure the last projectile spring contact interacts with the node that represents the muzzle of the gun.

4.1 Gun Model. Gun system information input includes the geometry and mass description of the gun barrel and breech, along with breech CG offsets, trunnion and elevation support locations, and their equivalent spring constants. The breech assembly of the EX45 Mod4 weighs 1,598 kg (3,521 lb). The axial location of the breech CG is 436.9 mm (17.2 in) from the rear face of the breech (RFB), and the breech CG with the breech block in the firing position is offset 5.49 mm (0.216 in) vertically and −2.72 mm (−0.107 in) horizontally. The trunnion supports are located 577.8 mm (22.75 in) forward of the rear face of the breech assembly and were assigned a spring constant of 5.6^8 N/m (3,200,000 lb/in). The effective elevation support of the gun assembly is located 1406.3 mm (55.68 in) forward of the rear breech face and was assigned a spring constant of 23.8^6 N/m (135,800 lb/in). The values for the spring constants of the trunnions and elevation support were supplied by UDLP and were derived from a finite element model used to analyze the gun structure under shipboard shock and vibrations.

4.2 Projectile Model. The projectile used in the firing tests is the standard Mk64 high-explosive round. This short wheelbase, stiff projectile body, shown in Figure 3, was modeled previously [5]. The physical properties of the Mk64 are length - 662.5 mm (26.082 in), weight - 31.61 kg (68.70 lb), and center of gravity - 420.6 mm (16.560 in) from the nose. The

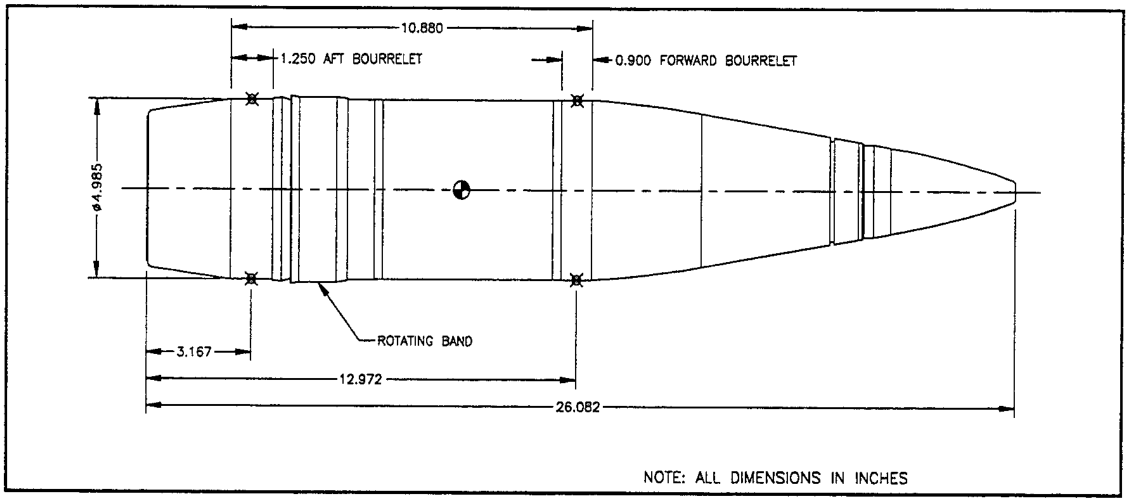

Figure 3. Mk64 5-inch Projectile.

required spring parameters are forward contact - 342.0 mm (13.46 in) from nose, forward spring - 2.08^8 N/m (1.185^6 lb/in), aft contact - 571.0 mm (22.480 in) from nose, and the aft spring - 1.97^8 N/m (1.125^6 lb/in).

5. Hypothetical Cases, Discussions, and Results

Major cannon-producing plants, such as the one in Louisville, KY, for the U.S. Navy, routinely practice pressing or bending cannon barrels in the manufacturing process. After the last major pressing operation, the barrel is rotated about the axis to find the muzzle high point, and then the barrel is indexed up. The evidence of what appears to be a hard bend just before the support point of 4,800 mm from the muzzle can be noted in Figure 2, but is best observed in Figure 4 where the vertical CL is displayed without gravity.

The first set of hypothetical cases starts with the original vertical CL with gravity, noted in Figure 2, and a modified CL called "low-slope," where the hard bend is removed. By constructing a straight line from the support to the muzzle and storing the differences, the remainder of the centerline can be reconstructed anywhere. In this case, as shown in Figure 4,

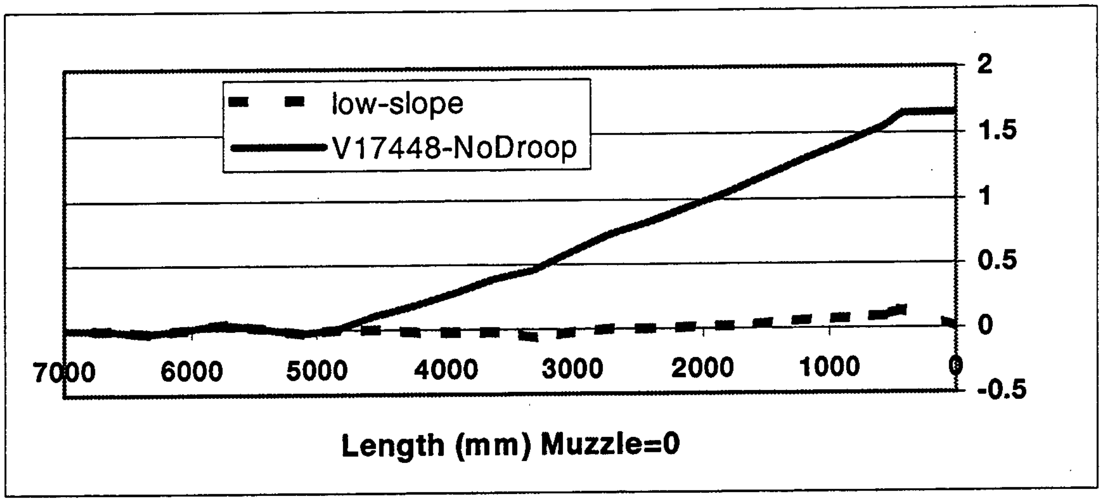

Figure 4. Gravity-Free Comparison of Original CL and Modified Low-Slope CL.

the low-slope line positions the muzzle at zero displacement. The last CL considered for this first set is the simple droop case, plotted in Figure 2.

For simplicity, only the projectile front contact forces will be presented in this report. The forces are shown in the time domain. (Note that the projectile front contact reaches the bend 7.4 ms after shot start.) The projectile front contact forces in Figure 5 show that there is a reduction in magnitude for the two CLs other than the original v-17448 CL. However, the force response for the low-slope case is not significantly different from the original case. There was an expectation of a reduced magnitude in the lateral force for the low-slope case. The forces for the droop-only CL case produce the lowest lateral loads and probably represent a best-case scenario because this CL is a low frequency smooth curve.

The CLs of Figure 2 are displayed again in Figure 6 with scales changed to show a closeup of the first 2.5 m of projectile travel. In Figure 6, the CL has a peak-to-peak sinusoidal wave in this region of only 0.1 mm. This small sinusoidal wave causes the first 7.4 ms of lateral disturbances.

To determine the magnitude of the disturbance force due to the bend, a hypothetical case is made up in which the first 2.2 m of the CL without gravity is not allowed to deviate from the

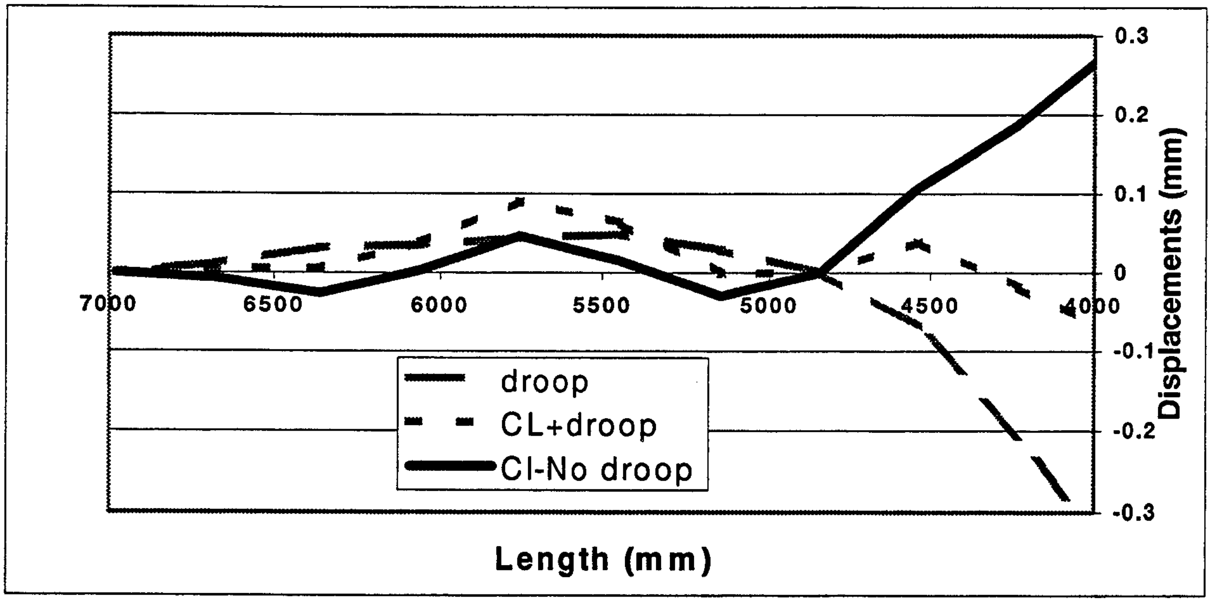

Figure 5. Interaction Forces for Original, Droop Only, and the Low-Slope CLs.

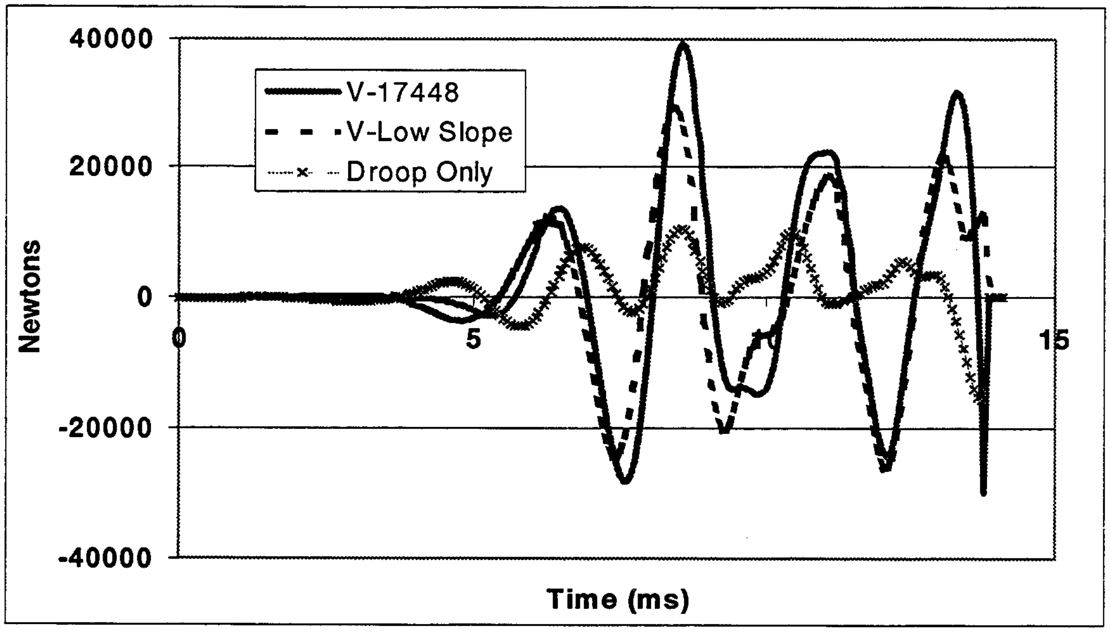

Figure 6. A Small Sinusoidal Shape Evident in the CL Between the Supports.

axis.* Next, with gravity applied to this straightened hypothetical CL, the first 2.2 m of the projectile travel follows the droop curve before the projectile front contact meets the bend point. These hypothetical centerline cases are illustrated in Figure 7.

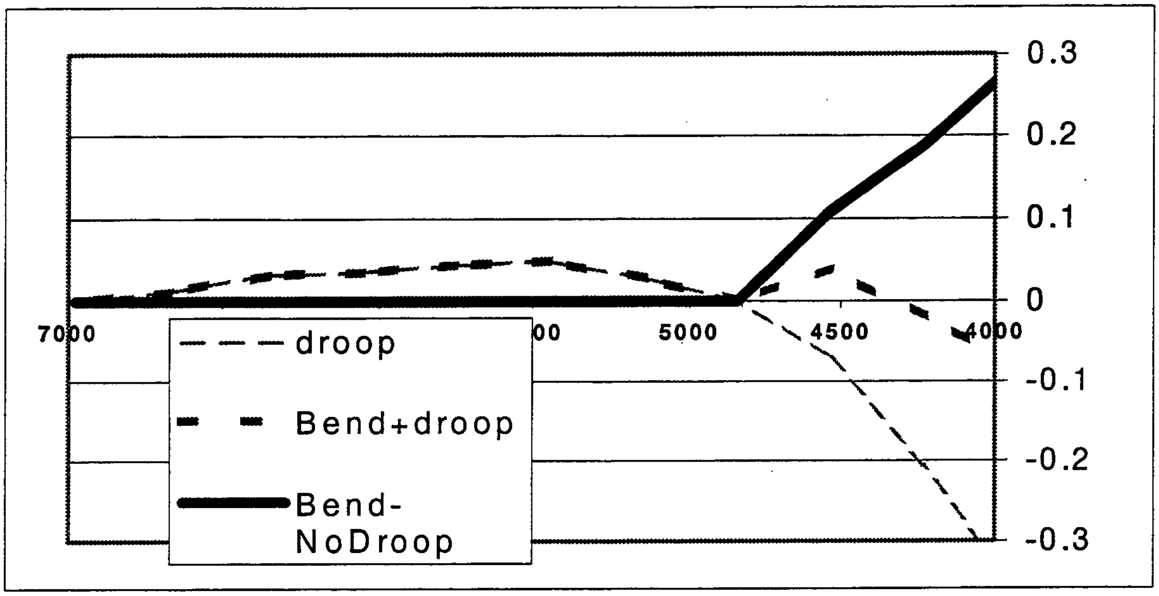

Figure 7. A Modified CL Isolates the Bend and Removes the Small Sinusoidal Shape.

In Figure 8, the barrel-projectile interaction forces are shown in the vertical plane for three CL cases. Two of the cases are from the hypothetical cases shown in Figure 7, the simple droop CL and the isolated bend CL, and the third is the original CL. In this example, the projectile interaction forces of the isolated bend case follow the droop case until the bend is encountered, then the peak of the isolated bend case falls significantly in comparison. However, the peak of the original CL case is significantly greater than both of the other cases. Since the forces noted for the original CL are about two times higher than the isolated bend case, the small sinusoidal shape preceding the bend is amplifying the force response. The small sinusoidal wave in the original CL initiates an earlier force response which exacerbates the force magnitudes throughout the entire in-bore loading cycle.

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* This removes the sinusoidal wave during the initial travel and isolates the bend.

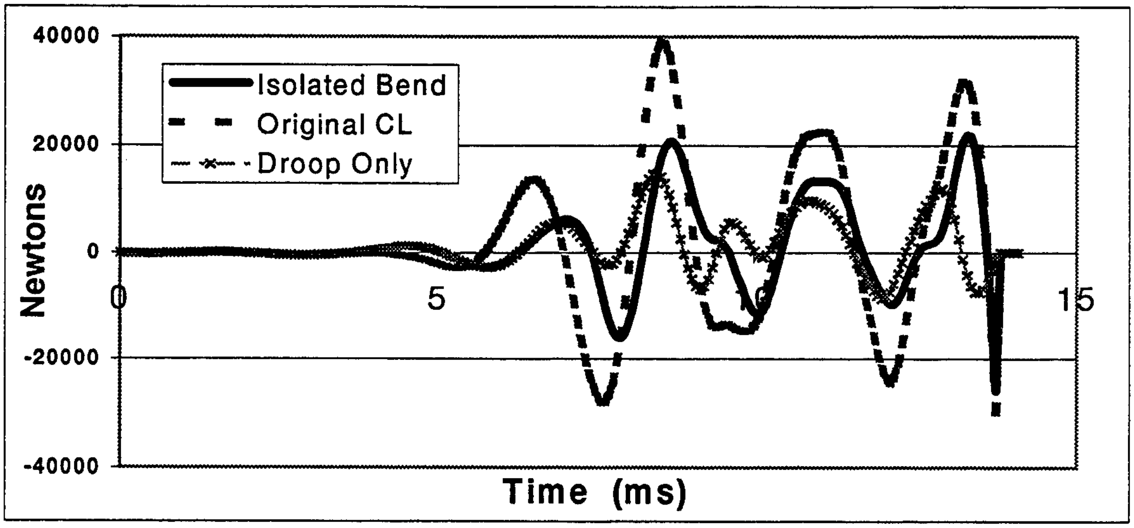

Figure 8. Comparison of the Isolated Bend Forces to the Original Forces and Droop Only.

After eliminating the force response due to gravity droop, the following hypothetical cases are compared in a gravity-free field: the isolated bend CL (noted in Figure 7), the original CL (Figure 4), and the low-slope CL (Figure 4). The forces for these cases, shown in Figure 9, are most interesting because the two curves that contain the small sinusoidal shape (the original CL and the low-slope CL) have their forces almost entirely overlapping each other. The simple isolated bend case forces start later in the in-bore cycle and present lower magnitudes than the other two cases.

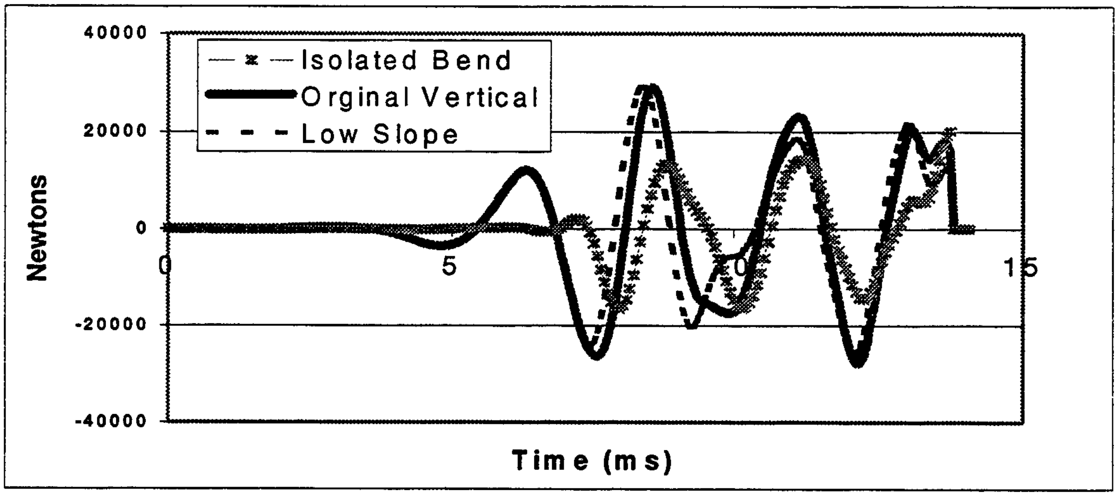

Figure 9. Gravity-Free Comparison of Forces: Isolated Bend CL, Original CL, and Low-Slope CL.

6. Conclusions

The prototype 62-cal. naval cannon (S/N 17448) was analyzed with the Little RASCAL gun dynamics program. To examine the barrel-projectile interacting forces, hypothetical cases were used for removing the bend and what was originally believed to be an insignificant, small sinusoidal variation in the centerline preceding the bend. This analysis suggests that

- a single, isolated bend in a gun barrel centerline may not be conducive to generating large lateral loads, but

- a small sine wave in a gun barrel centerline can significantly amplify lateral loads.

The Little RASCAL program is an ideal vehicle for running many hypothetical cases. Even though the Little RASCAL is a first-order analysis code, it is likely that higher-order numerical solutions would yield similar trends.

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A naval cannon was analyzed with the Little RASCAL gun dynamics program to predict shot exit conditions. There appeared to be a sharp manufacturing bend in the barrel's vertical plane. The Little RASCAL program makes modeling many hypothetical cases easy. This report compares the projectile and barrel interacting forces with and without the effects of the sharp bend. More importantly, a small sinusoidal variation in the deviation of the barrel centerline preceding the sharp bend presents itself as a detrimental factor by amplifying the lateral forces.

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