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EFFECT OF A BORE EVACUATOR ON PROJECTILE IN-BORE DYNAMICS

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14. ABSTRACT

Projectile base pressure measurements were taken in a 155-mm M284 gun tube using an Armament Research, Development and Engineering Center-designed instrumentation package incorporated into a modified XM982 artillery projectile. These measurements showed that the base pressure was affected as the projectile passed the bore evacuator ports. The perturbation in base pressure generated a high frequency response in the projectile. A simplified finite element model of the projectile was constructed and verified that the projectile dynamics were captured properly by the instrumentation. A dynamic response was also witnessed at abrupt changes in gun tub cross-section. This response has not been explained to date.

15. SUBJECT TERMS

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INTRODUCTION

The guns on the tanks and howitzers that carry soldiers include a device called a bore evacuator. A bore evacuator expels propellant gases that could otherwise harm the crew. The bore evacuator also changes the pressure pulse and the accelerations along the length of the projectile.

As the use of electronic devices increases in gun-launched projectiles, the designer is more and more interested in dynamic events that result in failure of these components. This interest in component failure has led the engineering community to look closely at the dynamic aspects of gun launch through both modeling and instrumented firings. In the past, when components were primarily mechanical, it was sufficient to examine the pressure-time history of a worst case launch, perform quasi-static analysis using peak accelerations as the input, apply a safety factor and design away. Since the failure of sensitive electronic components has been found to be highly dependent upon the frequency of the loading, this quasi-static approach is only valid for a "first cut" at the design.

This interest in the dynamics of the gun launch has increased the use on on-board instrumentation in test firings. This on-board instrumentation has been configured in various tests to measure accelerations, strains, and pressures as well as send signals on the performance data.

Data obtained from on-board instrumentation used in 155-mm howitzer firings indicate that critical electronic components tend to fail primarily during the muzzle exit transient. During the exit of the projectile from the muzzle, the base pressure drops very rapidly (~0.1 ms). This sets up axial and radial ringing in the projectile, which can occur at the natural frequencies of the electronic devices causing failure.

If one examines data from many firings, one can observe axial and lateral vibrations in the projectile nearly 2 ms prior to the muzzle exit transient. This behavior was observed to be of higher magnitude when a bore evacuator was present. Two theories (both of which we believe are correct and additive) to explain this behavior were postulated. The first theory was that interaction of the axial stress waves caused by the projectile motion with the gun tube caused the behavior. The second theory was that the bore evacuator caused a pressure spike on the base of the projectile.

The interaction of gun tube stress waves with the projectile has been observed in tests in the past (ref. 1). This mechanism comes about through the dilation and axial load placed on the tube by the projectile-charge combination. The stress imparted on the tube by the projectile is fairly large. Axial stress waves cause radial waves through poisson effects. At abrupt decreases in tube cross-section, the interaction of the radial waves intensifies, coupling into the projectile response. This phenomenon appears to increase as the quadrant elevation (QE) of the weapon is decreased, possibly indicating some bending modes are affected.

Instrumented tests on the M203A5 howitzer (ref. 1) (using an M284 tube) have shown a greater intensity of radial excitement in the tube after the passage of the bore evacuator holes. This behavior (and other program concerns) required the development of an instrumented base projectile. This projectile contained both accelerometers and pressure transducers in the base. It was interesting to note that a pressure spike occurred as the projectile passed the bore evacuator holes and this corresponded to the increase in dynamic activity of the projectile. It is the intent of this paper to describe the discovery of this phenomenon.

EXPERIMENTAL

A test was conducted at Yuma Proving Ground, Yuma, Arizona using an M284 155-mm cannon with five instrumented projectiles as described in reference 2. The projectiles contained nine PCB 109A12 ballistic pressure gages and a tri-axial accelerometer package consisting of Endevco 7270A-20k accelerometers. The projectiles were fired at ambient temperatures using M4A2 bag charges, PXR6297A1 bag charges, and Modular Artillery Charge System (MACS) - 5 charges. The rounds were all fired at a QE of 450 mils. Figure 1 depicts the geometry of the gun tube including the location of the bore evacuator holes.

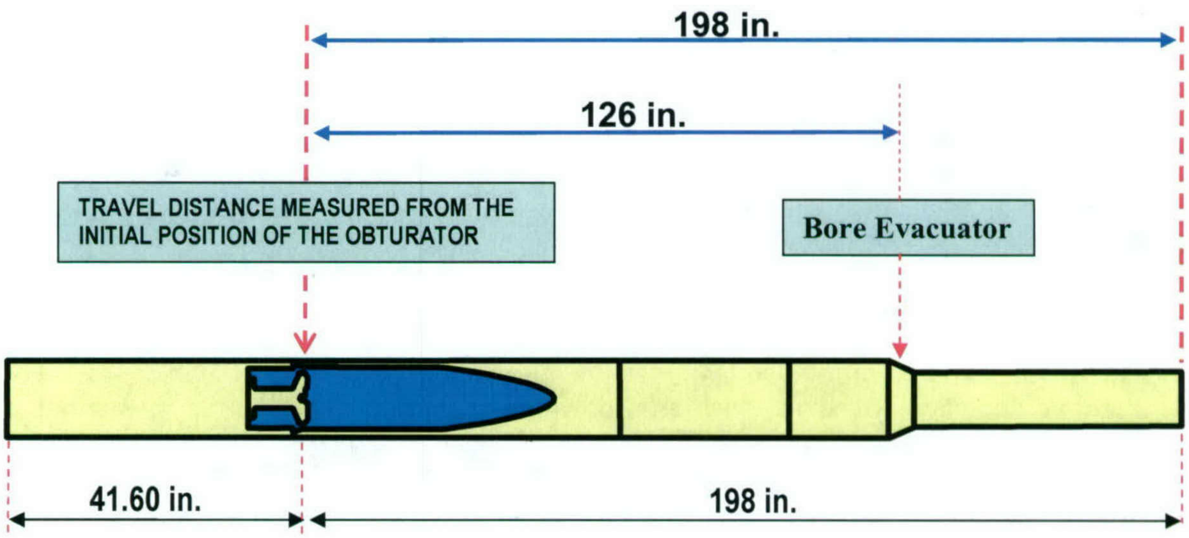

Figure 1
M284 gun tube geometry

EXPERIMENTAL RESULTS AND DISCUSSION

Tube round number (TRN) 81 was fired using an M4A2 charge. Figure 2 is a plot of the acceleration versus time from this firing. The axial acceleration is of the greatest interest in this figure. A look at the axial data clearly shows an acceleration spike shortly after 15 ms. Figure 3 shows the velocity and displacement of the projectile superimposed on the acceleration-time curve. The beginning of the dynamic behavior occurs around 125 in. from the seating location of the projectile in the weapon's forcing cone. This is approximately where the bore evacuator holes are located. Figure 4 is a plot of axial acceleration and base pressure data. It is clear in this plot that the pressure discontinuity initiates the dynamic behavior in the projectile.

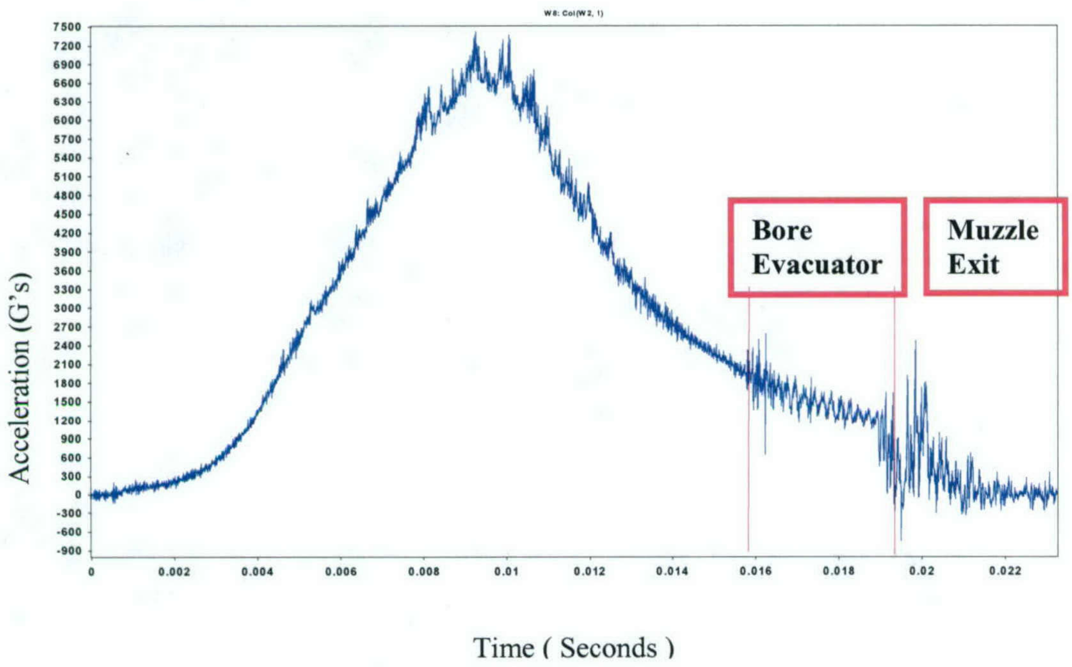

Figure 2
Axial acceleration versus time – TRN 81

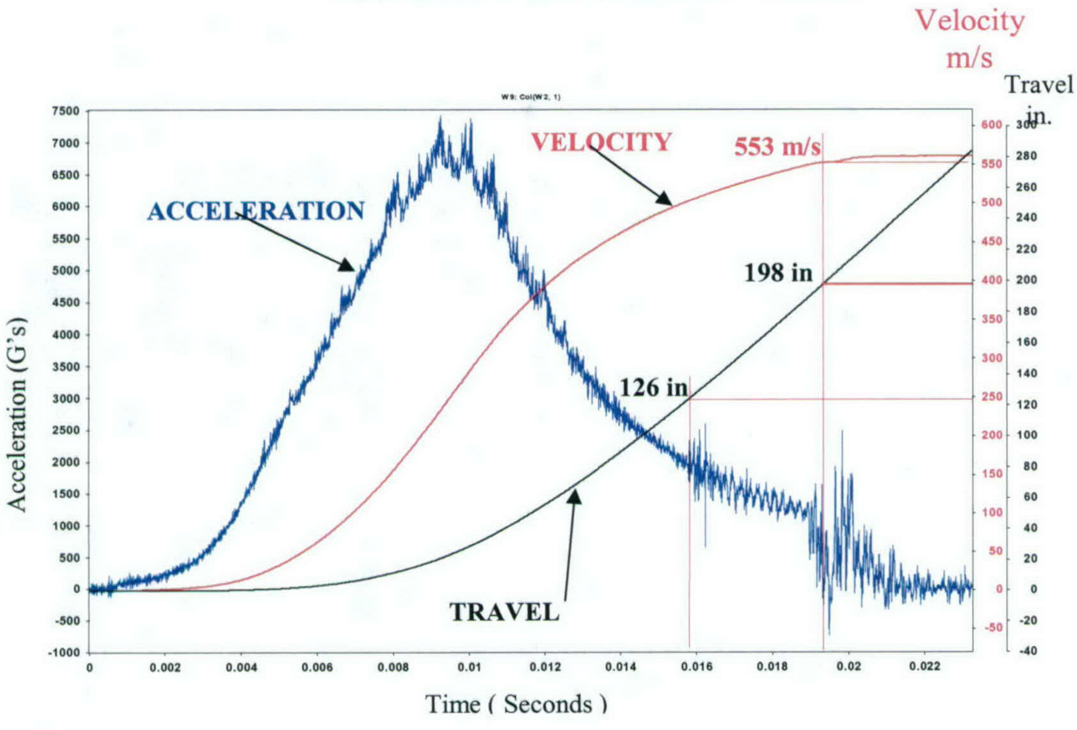

Figure 3
Projectile velocity, travel, and accelerations versus time – TRN 81

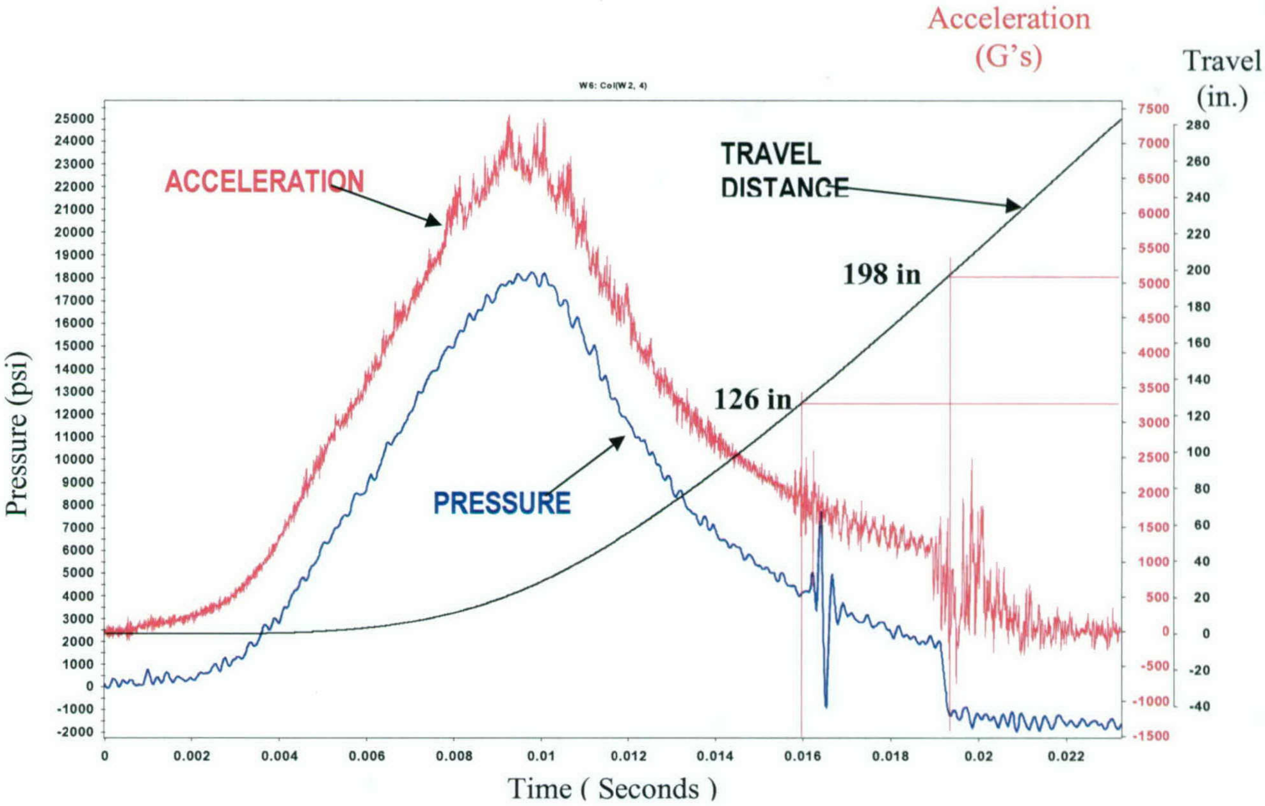

Figure 4
Pressure versus acceleration – TRN 81

TRN 82 was fired under the same conditions as TRN 81. Figure 5 is a plot of the acceleration versus time from this firing. This time the acceleration spike occurs shortly after 16 ms. Figure 6 shows the velocity and displacement of this projectile with the acceleration-time curve. The beginning of the dynamic behavior again occurs around 125 in. from the seating location of the projectile. Figure 7 portrays axial acceleration and base pressure data. Unlike the data for TRN 81, there is no definitive pressure spike that we have detected that initiates the dynamic behavior. Examination of this data indicates that the dynamics begin at the last abrupt change in gun tube cross-section. There are several postulated mechanisms for this reaction, though none were proven definitively.

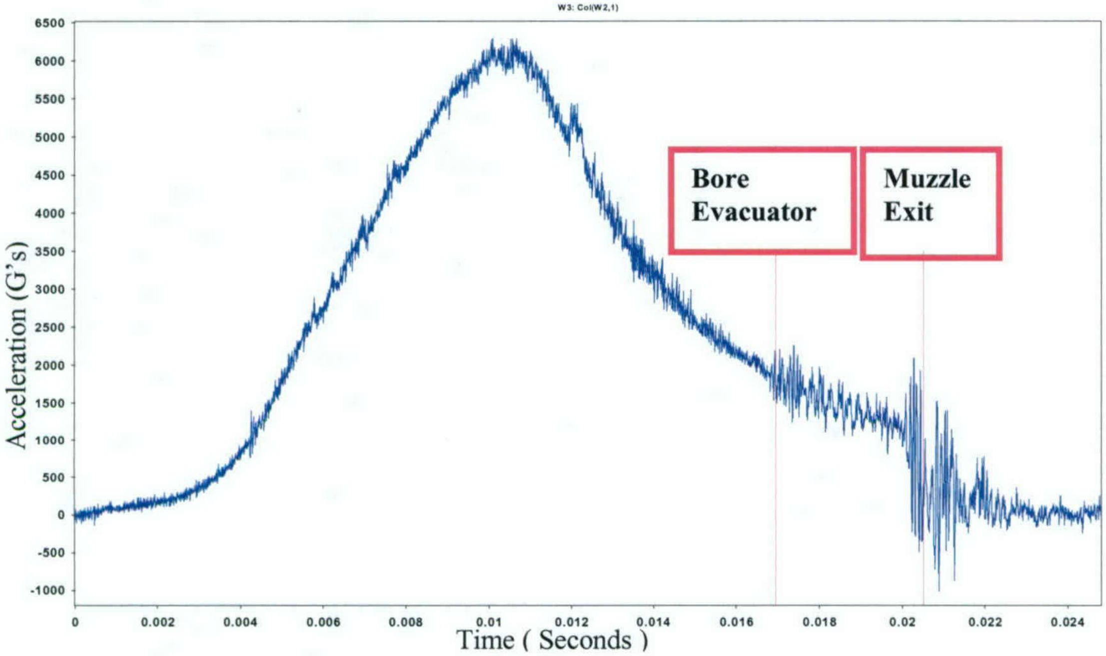

Figure 5
Axial acceleration versus time – TRN 82

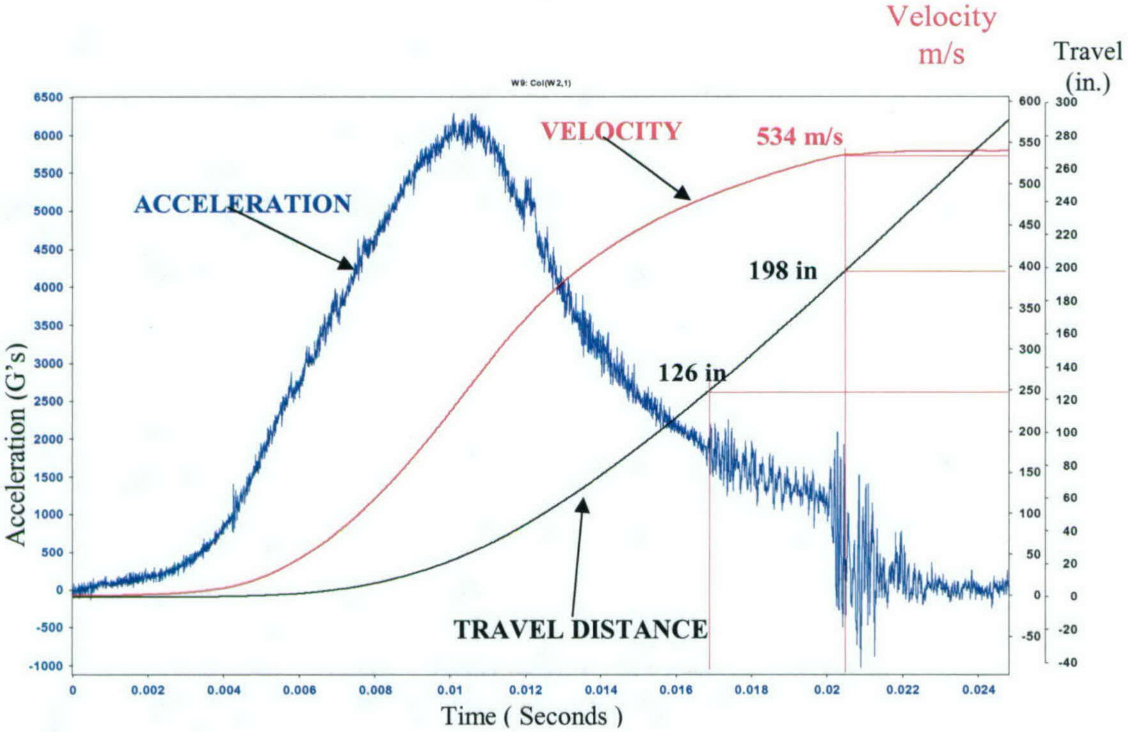

Figure 6
Projectile velocity, travel, and acceleration versus time – TRN 82

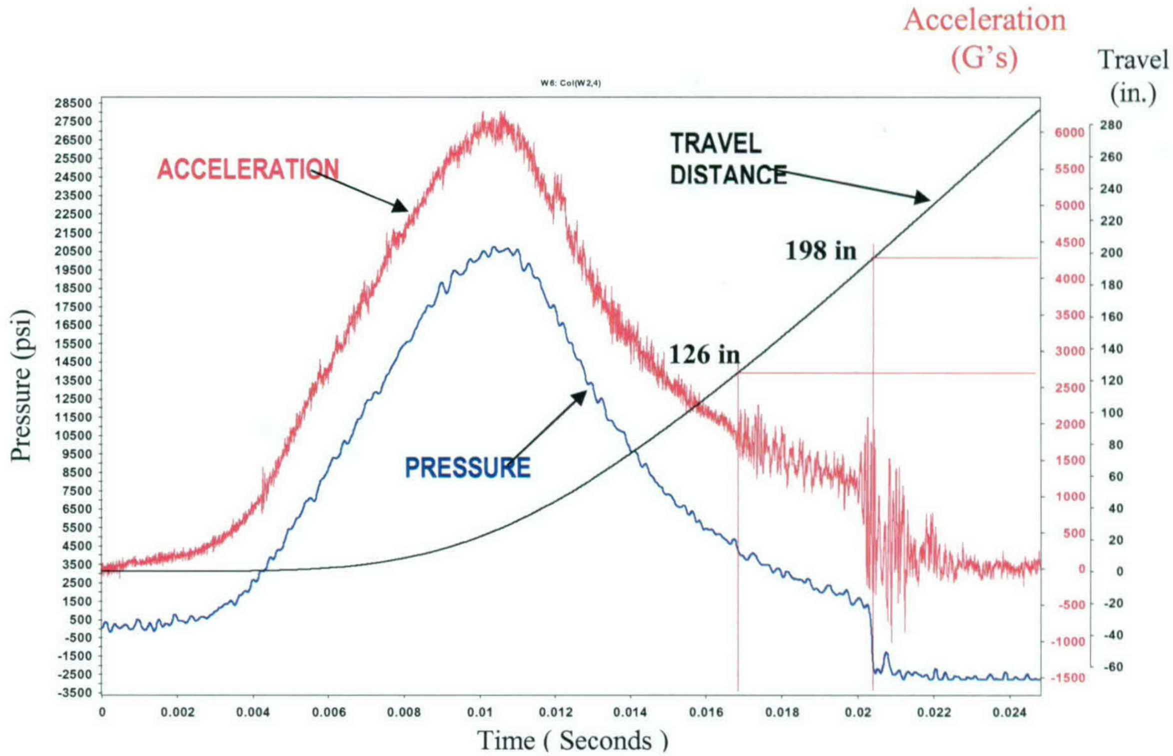

Figure 7
Pressure versus acceleration – TRN 82

NUMERICAL RESULTS AND DISCUSSION

A simple projectile model was used to evaluate the accelerations and forces caused by the bore evacuator in an M284 gun tube (ref. 2). Table 1 summarizes the length, weight, and stiffness of the projectile. The projectile had an outside diameter of 155 mm. The gun is about 6100-mm long. Figure 8 shows the gun and projectile.

Table 1
Simple projectile model

Section	Material	Young's Modulus (GPa)	Poisson's Ratio	Weight (kg)	Length (mm)
Base	steel	200.2	0.32	10.3	166.4
Payload	steel	200.2	0.32	27.7	424.2
Control section	steel	200.2	0.32	7.0	159.6
Nose	aluminum	69	0.3	3.2	243.1

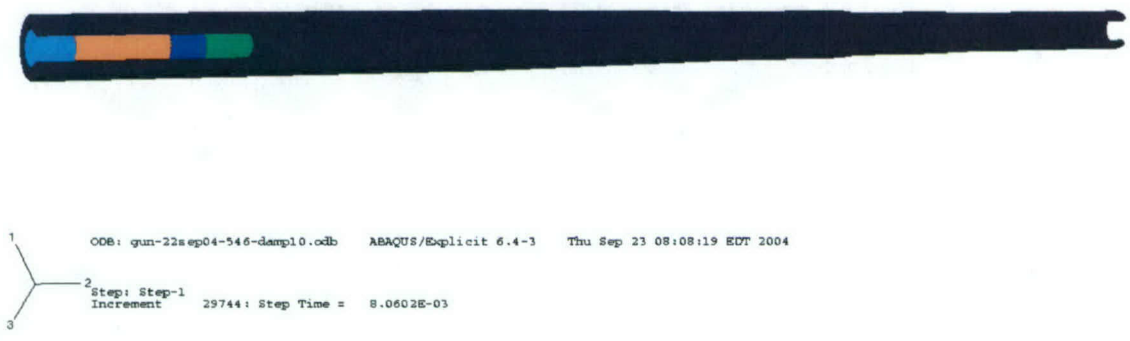

Figure 8
Simple projectile model with M284 gun (all parts 360 deg in analysis)

The gun and projectile were modeled using the general purpose finite element package, Abaqus Explicit. Eight node brick elements were used for the analysis. All parts were modeled as linear-elastic. Abaqus's alpha-type damping was used in the solid elements. Alpha was based on 5% critical damping at a frequency of 2000 Hz; alpha was 1256. It was also assumed that 5% critical damping existed between the projectile and the gun. The axial and transverse accelerations were calculated and compared to accelerations recorded by the on-board recorder for shot S81.

Acceleration was applied to the base of the projectile in the axial direction. The acceleration was scaled from the pressure curve shown in figure 4. The scaling factor accounted for the projectile weight plus 5% increase to account for the obturator diameter and blow-by. The scaled acceleration is shown in figure 9. To determine the effect of the bore evacuator, the acceleration in figure 9 was altered by removing the bore evacuator perturbation (fig. 10). In addition to the acceleration load, a pressure load was used to model a non-axi-symmetric pressure on the outer diameter of the projectile. The side load was applied as pressure over one-quarter of the model and followed the pressure curve with a scaling factor of 0.05, assuming 5% unequal distribution of pressure.

— G2 at Input BoreEvac Blowby5-5

XMIN 0.000E+00
XMAX 2.600E-02
YMIN 0.000E+00
YMAX 6.646E+03

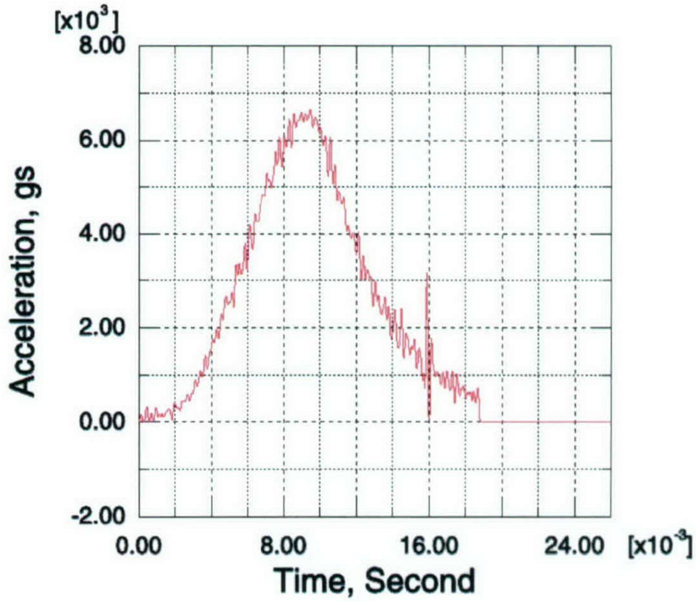

Figure 9
Input accelerations with bore evacuator

— G2 at Input NoBoreEvac Blowby5-5

XMIN 0.000E+00
XMAX 2.600E-02
YMIN 0.000E+00
YMAX 6.646E+03

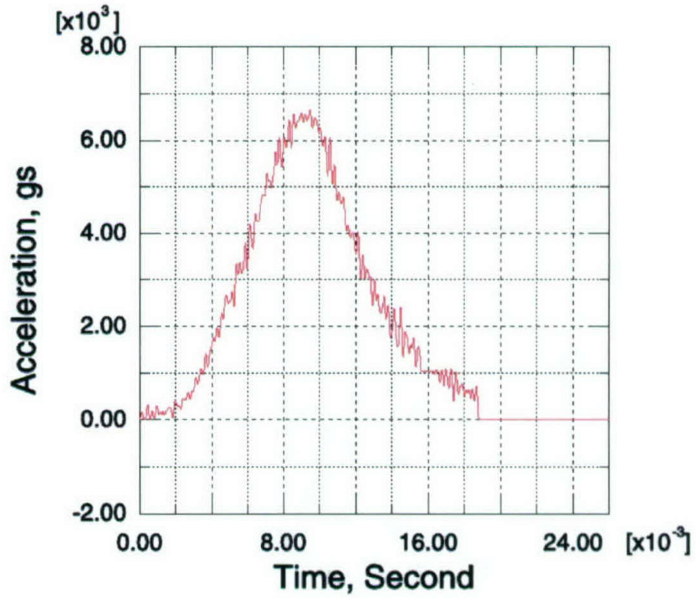

Figure 10
Input accelerations without bore evacuator

Results are shown in figures 11 through 14. Figure 11 shows the difference in the predicted axial acceleration with and without the effect of the bore evacuator. When the projectile passes the bore evacuator location, additional reversing accelerations in the axial direction are noted for the bore evacuator load. Figures 13 and 14 shows the transverse accelerations with and without the bore evacuator effect. For clarity, the recorded experimental acceleration is shown as negative. As shown in Figure 14, the effect of the bore evacuator is a transverse acceleration pulse of about 7300 gs. The predicted pulse was 1500 gs in the transverse direction, lower in magnitude. With higher blow-by pressures, the predictions increased up to about 9000-gs for a 25% blow-by pressure.

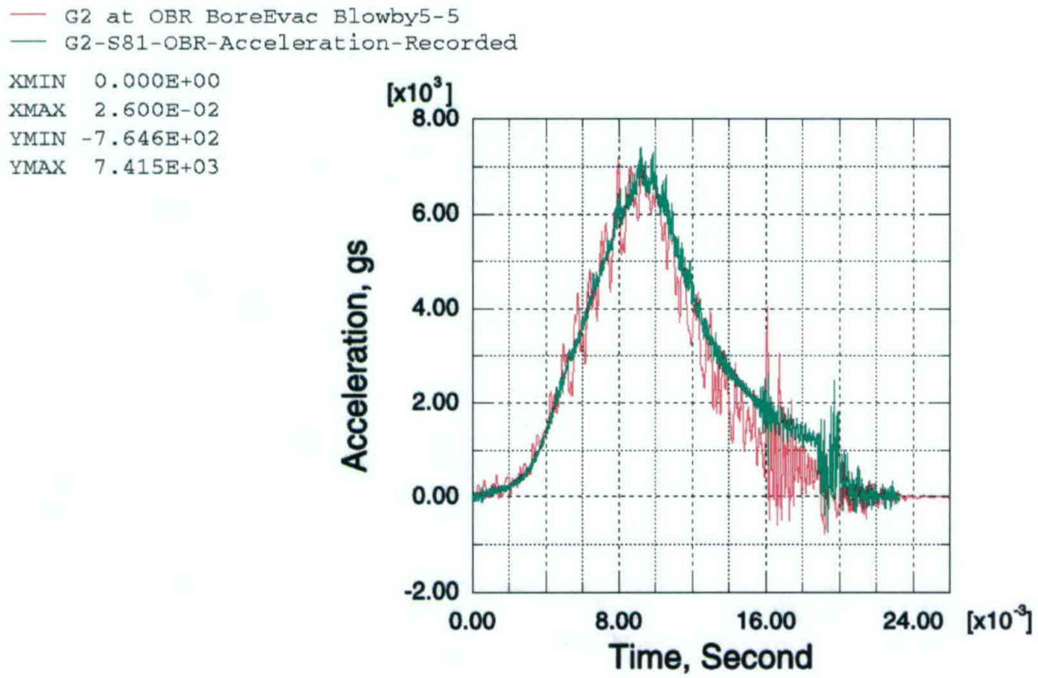

Figure 11
Predicted axial accelerations with bore evacuator

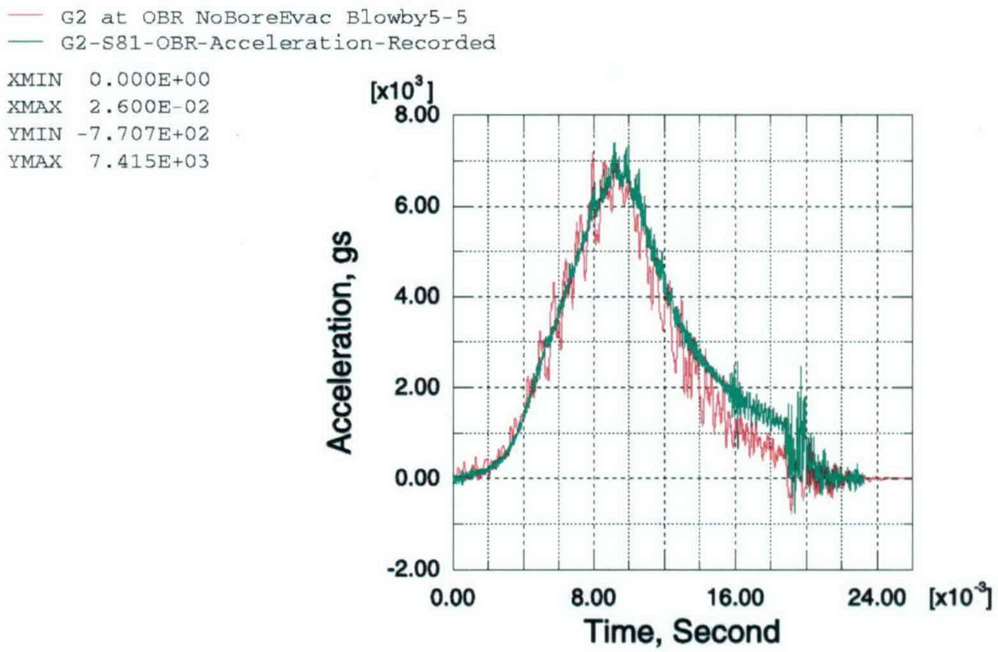

Figure 12
Predicted axial accelerations without bore evacuator

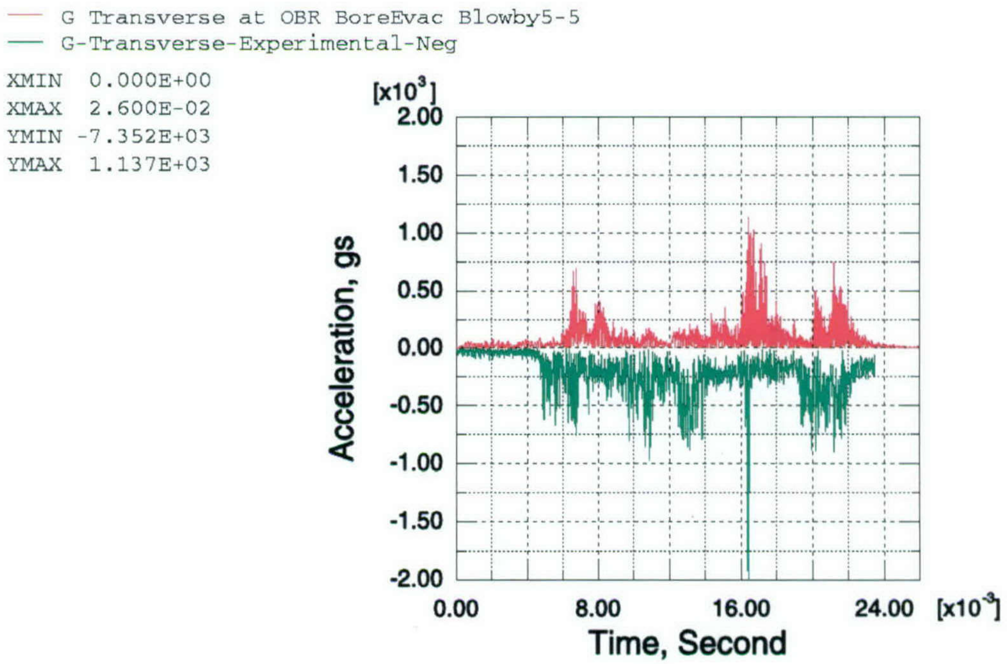

Figure 13
Transverse axial accelerations with bore evacuator

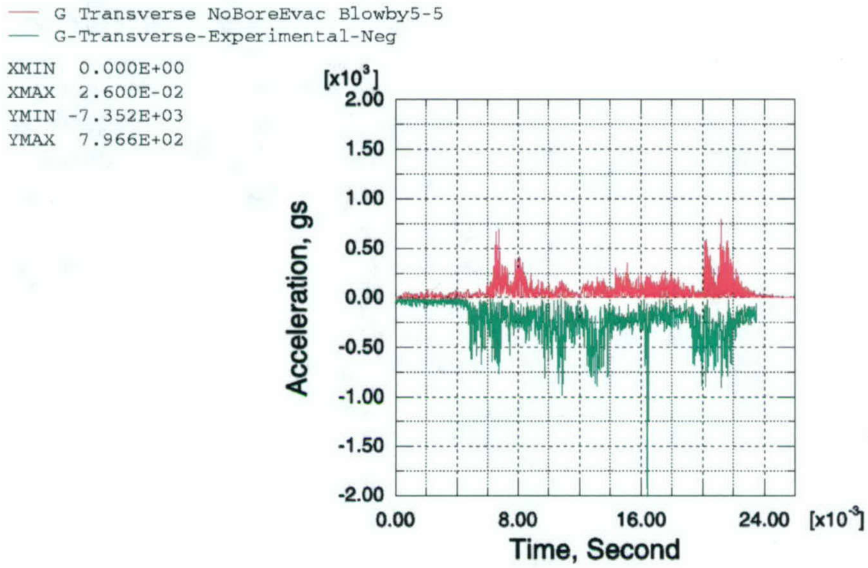

Figure 14
Transverse axial accelerations without bore evacuator

Figure 15 shows the contact force on the projectile base. The transverse accelerations at the bore evacuator are probably the result of the projectile hitting the gun as indicated by the transverse contact forces. It is not yet understood why the contact forces and transverse accelerations increase at about 0.005 sec. In the analysis, the effect did not occur without the transverse pressure, the assumed non-axi-symmetric load, on the projectile.

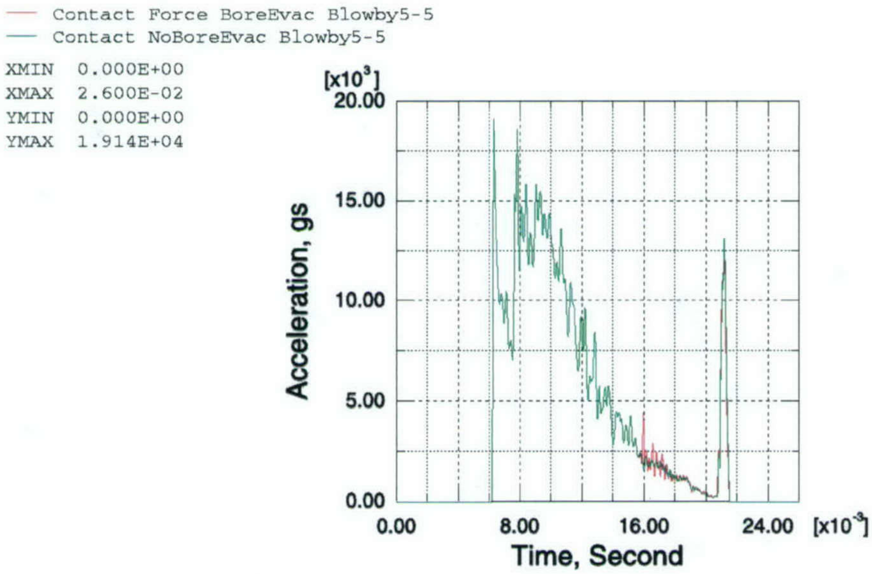

Figure 15
Transverse contact force with and without the bore evacuator

CONCLUSIONS

Measured base pressures appear to spike at the point in projectile travel where the bore evacuator is located in the M284 cannon. This pressure spike begins a ringing in the projectile that can have adverse effects on electronic components. A finite element model was performed using a simple projectile and the behavior was replicated. Observations have also been made that dynamic activity in the instrumented projectiles increases at changes in gun tube cross-section. This effect is most notable where the tube diameter decreases in the vicinity of the bore evacuator. This effect is not fully understood at this time.

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