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DESIGN ACCELERATIONS FOR THE ARMY'S EXCALIBUR PROJECTILE

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14. ABSTRACT

Excalibur is the Army's new 155-mm, guided projectile. It is scheduled for fielding in 2008. The objectives of Excalibur's test program are: 1) shake-out the weak systems for redesign by testing at a margin load, 2) characterize the gun-launch loads for design improvements and failure reviews, and 3) demonstrate structural integrity and operability after gun launch. In this paper, 10 live-firings at the margin load, PMP +5%, are presented. Averages, standard deviations, and statistical correlations are given.

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INTRODUCTION

The Army's XM982 Excalibur is a 155-mm projectile under development. The Army's development process includes live gun-firings at permissible maximum pressure plus 5% (PMP +5%) to validate safety, structural integrity, and operation (ref. 1 and 2). The PMP +5% load is also used to validate the design accelerations for Excalibur.

Each of the gun firings is instrumented to record the on-board accelerations. The gun tube is instrumented with pressure sensors. This paper summarizes the axial and transverse accelerations for PMP +5% firings of Excalibur. Statistical averages, variations, and confidence levels are presented. Test acceleration curves are presented to show the variation in dynamics from shot to shot. The shot to shot similarities and differences are used for failure investigations. Actual dynamic acceleration curves are also used for simulating the dynamic loads on components.

Other munitions have been instrumented to characterize gun-launch loads. Lee (ref. 3) was one of the first researchers to document the internal ballistics by instrumentation. In 1993, Lee published a paper describing seven live firings of a 155 mm with pressure transducers. Lodge and Dilkes (ref. 4) used accelerometers and displacement transducers to measure in-bore dynamics. Three projectiles were fired using a smooth-barrel, 120-mm gun. Wilkerson and Palathingal (ref. 5) reported an instrumented 120-mm M832E1 heat round. David, Brown, Myers, and Hollis (ref. 6) described some of the commercially-available equipment for measuring accelerations in different directions. Katulka, Pergino, Muller, McMullen, Wert, and Ridgley (ref. 7) recorded both axial acceleration and pressures on a 120-mm projectile. They used telemetry to transmit data. One resulting pressure and acceleration curve was presented in the referenced paper. While the acceleration curve had a different signature than Excalibur, some of the dynamics were similar to the Excalibur curves. Cordes, Vega, Carlucci, and Chaplin (ref. 8) reported the accelerations and correlated pressures for dozens of live-fire tests of Excalibur. This paper presents the recorded acceleration data for 10 PMP +5% loads for Excalibur. The data is used by the Army for design of the 155-mm Excalibur.

METHOD, GUN FIRINGS

Dozens of projectiles were fired from a soft-recovery vehicle. The tactical warhead section was replaced with a soft-recovery parachute system. The soft-recovery vehicle is about 1-m long and about 50 kg. The vehicle is designed to land without damage to components. For most firings, the soft-recovery vehicle has a base, control section, and forward nose similar to the tactical Excalibur design.

Figure 1 shows a sketch of the gun tube and soft-recovery vehicle. The projectile is initially seated about 0.9 m from the breech of the gun. The pressure sensor locations are listed as P1 through P7. Sensor P1 measures the breech pressure. Sensor P2 is close to the base of the projectile at shot start and estimates of base pressure up to the maximum axial acceleration. Pressure sensor 7 measures the muzzle exit pressure. Additional details regarding the pressure sensors are described by Hollis and others (ref. 9).

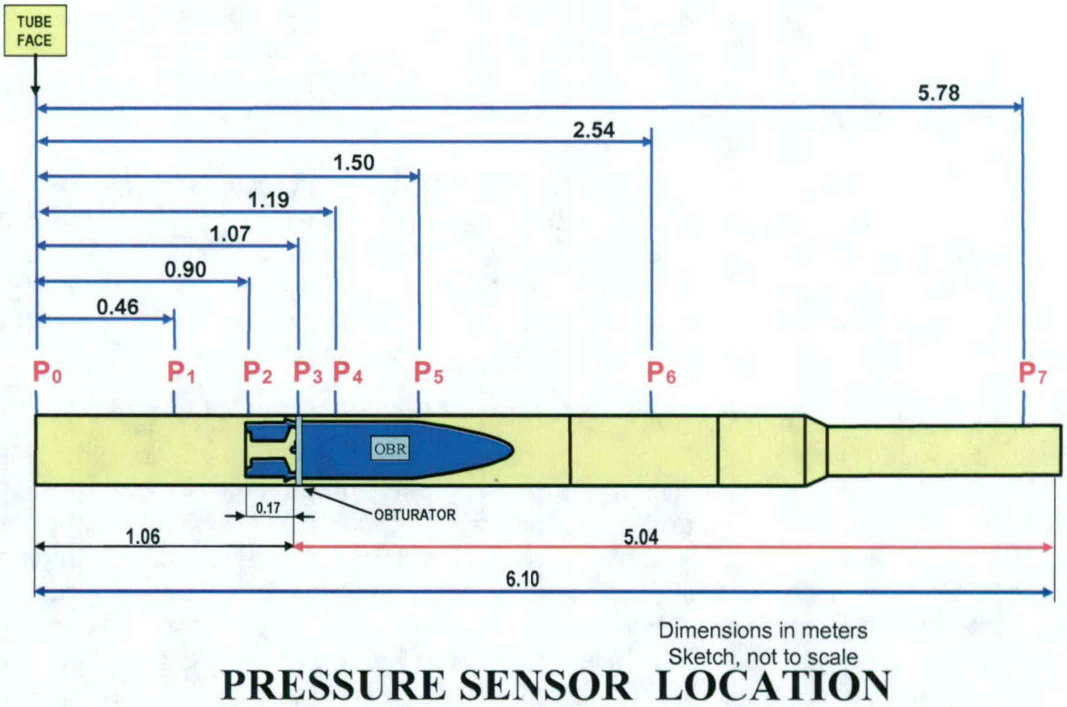

Figure 1
Gun tube, projectile, on board recorder, and pressure sensors

A representation of the soft recovery vehicle is also shown in figure 1. An on-board-recorder (OBR) is located about 0.5 m from the base of the soft recovery vehicle. In the OBR section, three perpendicular accelerometers measure accelerations in the axial and two transverse (balloting) directions. The sample rate is recorded at approximately 500,000 samples per second. A 50-kH, low pass, anti-aliasing filter is used. Accelerations are measured within the gun until muzzle exit.

RESULTS

Recorded Accelerations

The design loads for Excalibur are based on the Army's PMP +5% load. The PMP +5% refers to 105% of the maximum pressure allowable in a weapon as defined in International Test Operating Procedure (ITOP) 4-2-504 (ref. 2). PMP is a condition that is the 3-sigma upper limit on the service charge conditioned to +145°F. The PMP load corresponds to 13 in 10,000 firings. The PMP +5% can never happen in the field since it would require more charge than the PMP load. Live-fire, PMP +5% loads are used to shake out component failures in a development program. Instrumentation on the round is used to validate the design loads in the Excalibur environmental specification.

Figures 2 through 11 show the recorded accelerations in the axial and transverse directions for 10 PMP +5% firings. Transverse accelerations were recorded in perpendicular directions that are fixed to the rotating projectile. The data curves are relatively smooth near the maximum acceleration or 'set back' occurring at about 0.004-sec for the OBR3 case (fig. 2). Muzzle exit occurs at about 0.012-sec. At muzzle exit, high-frequency, reversing acceleration occurs in the transverse and axial direction. The 'set forward' acceleration corresponds to the minimum axial acceleration (in the opposite direction to the set back acceleration) and occurs at muzzle exit. The balloting acceleration is the transverse acceleration. It occurs as the projectile passes down the tube and laterally impacts the walls of the gun.

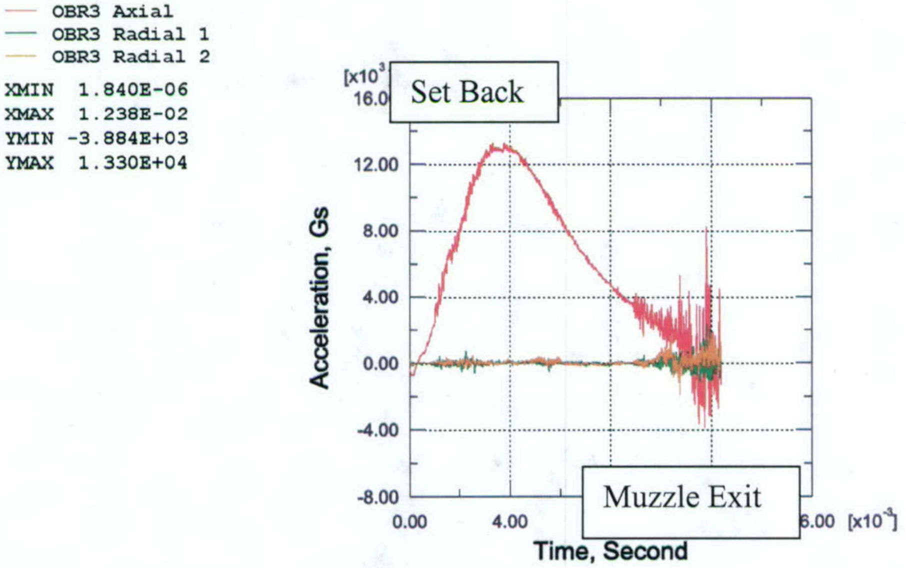

Figure 2
Recorded acceleration, PMP +5%, case OBR3

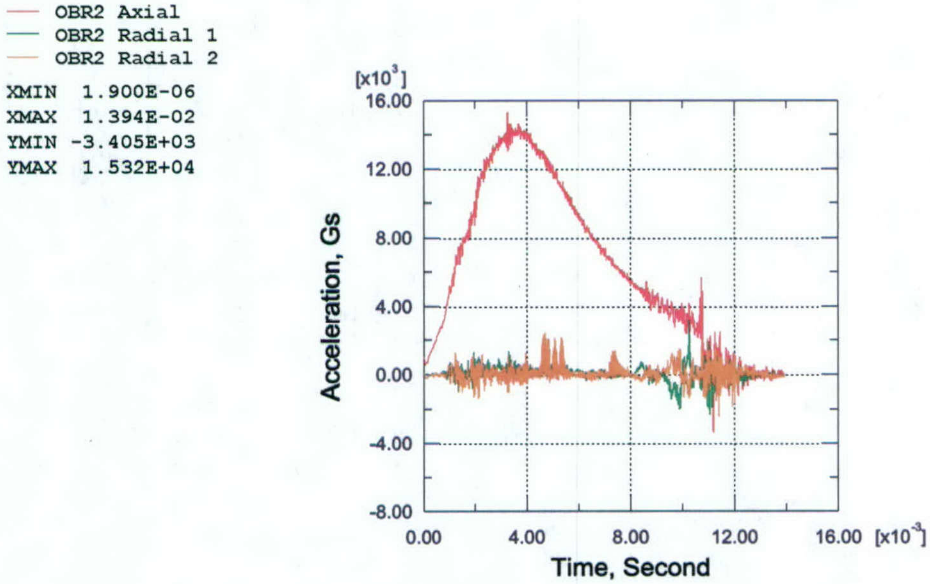

Figure 3
Recorded acceleration, PMP +5%, case OBR2

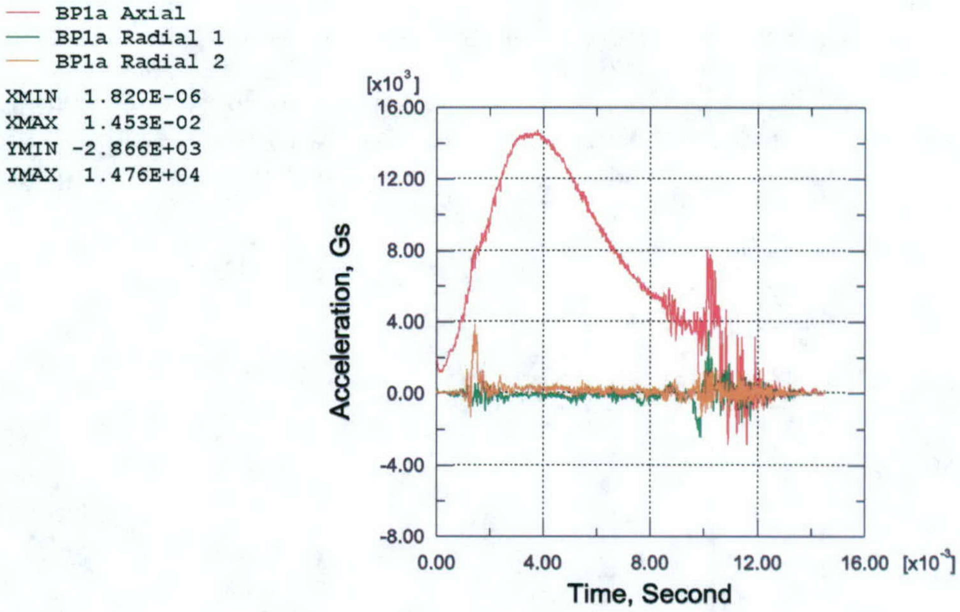

Figure 4
Recorded acceleration, PMP +5%, case BP1a

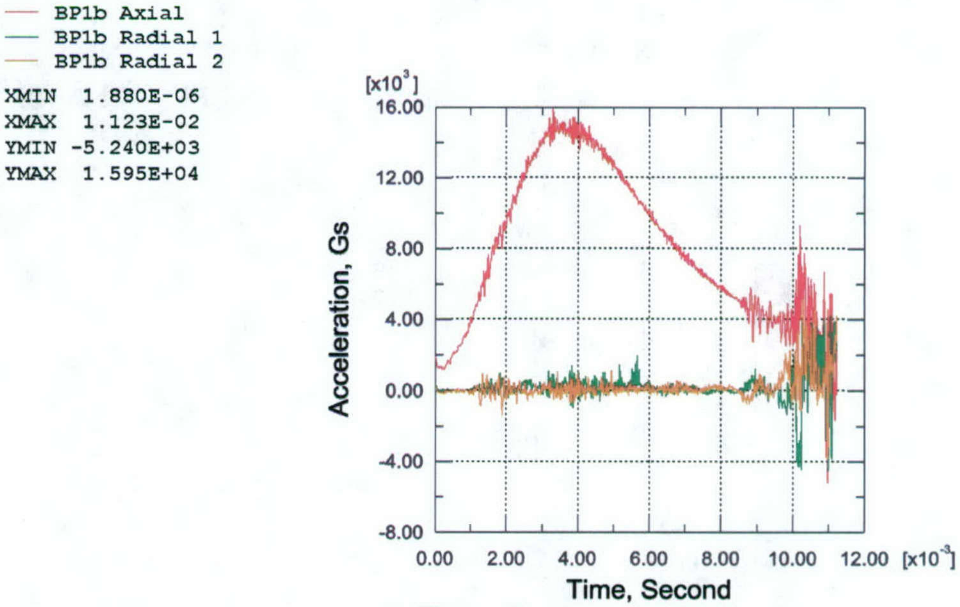

Figure 5
Recorded acceleration, PMP +5%, case BP1b

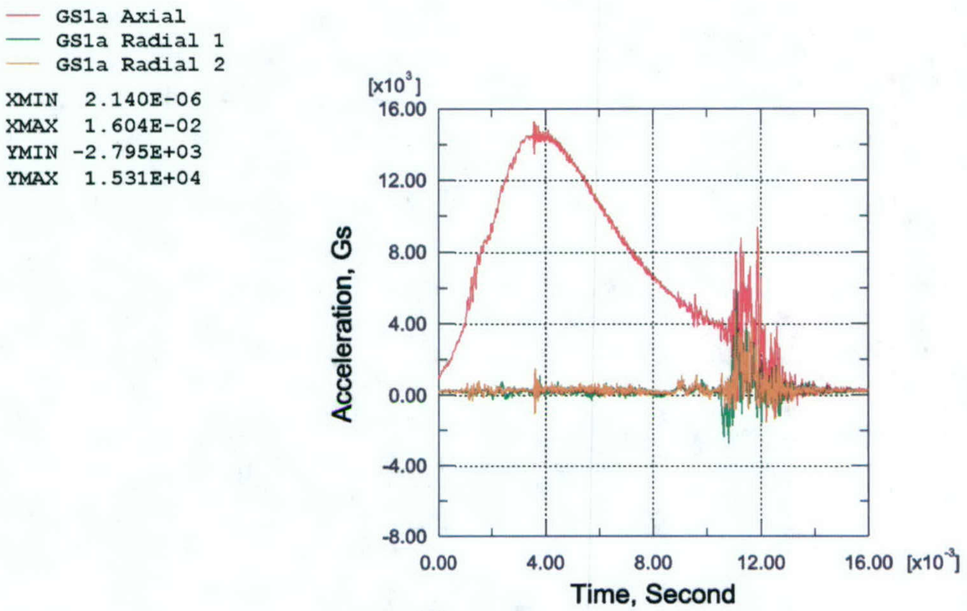

Figure 6
Recorded acceleration, PMP +5%, case GS1a

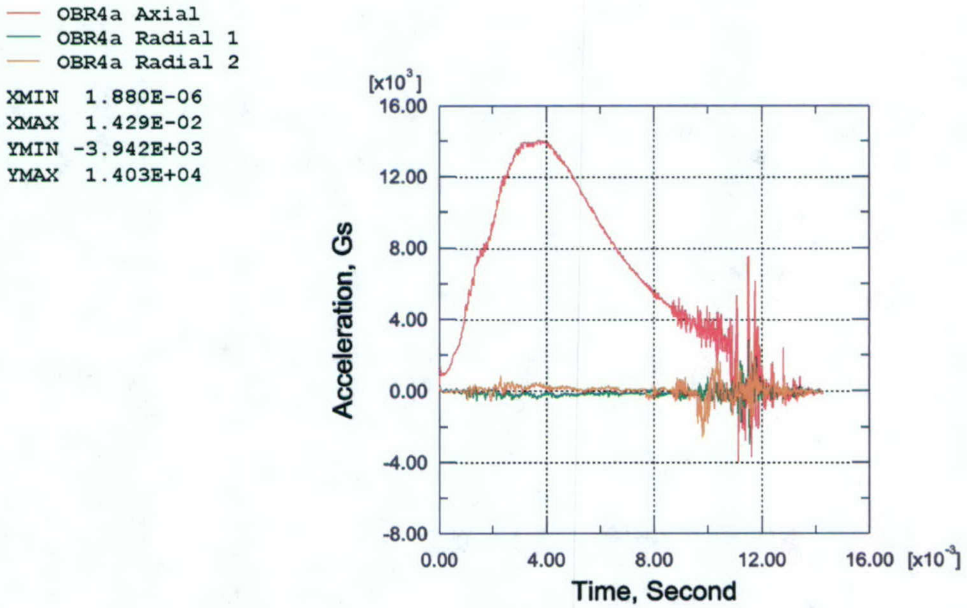

Figure 7
Recorded acceleration, PMP +5%, case OBR4a

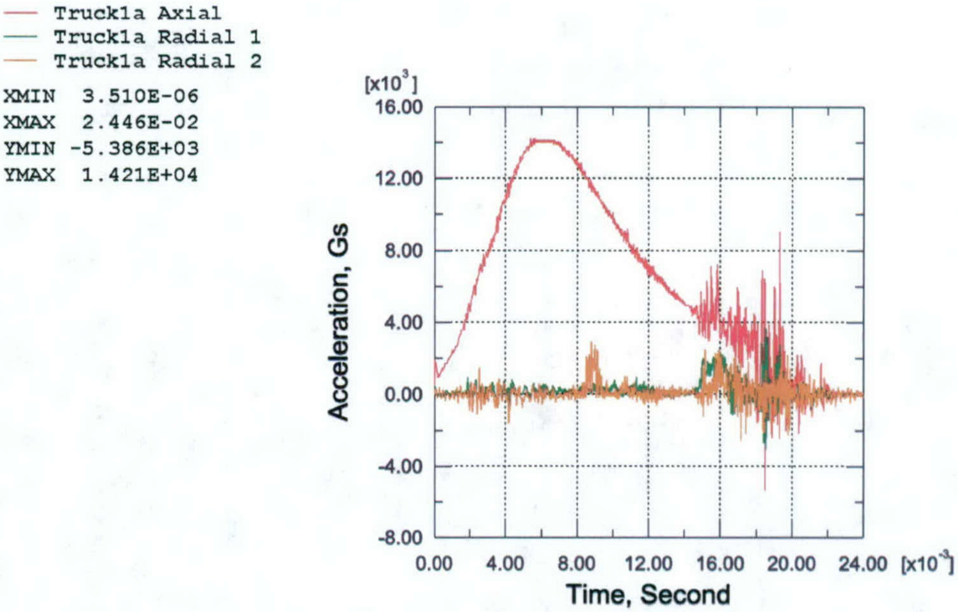

Figure 8
Recorded acceleration, PMP +5%, case Truck1a

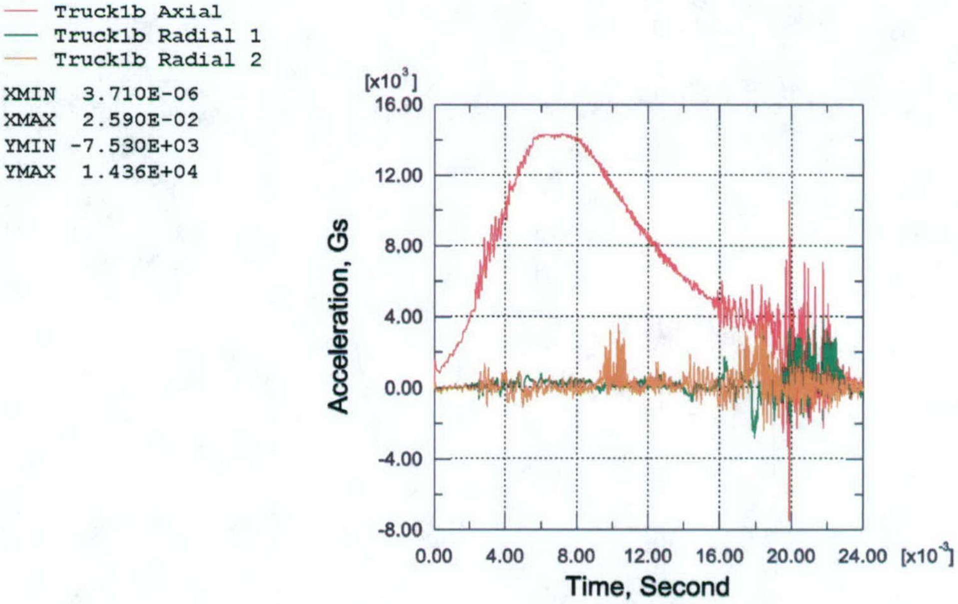

Figure 9
Recorded acceleration, PMP +5%, case Truck1b

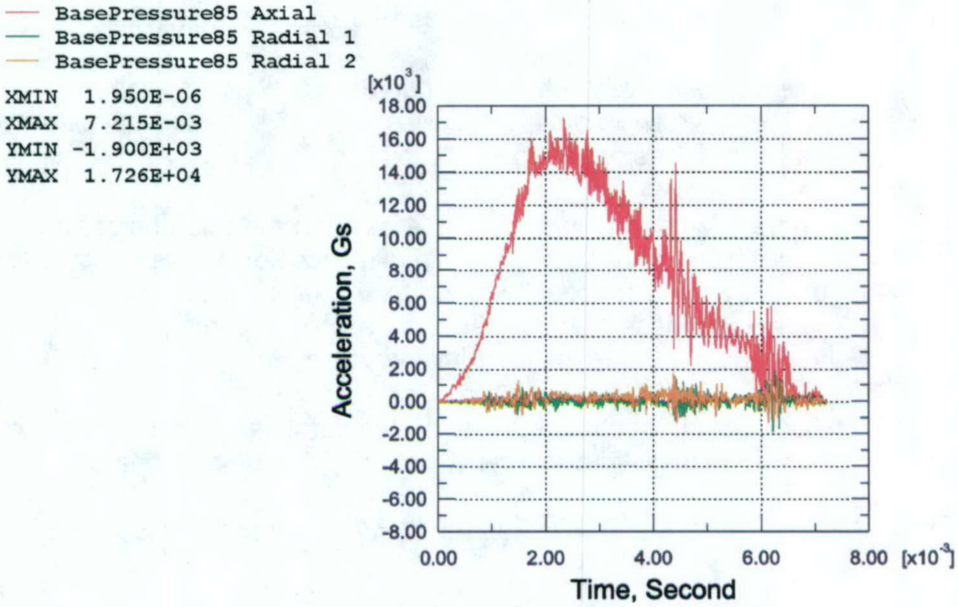

Figure 10
Recorded acceleration, PMP +5%, case BasePress85

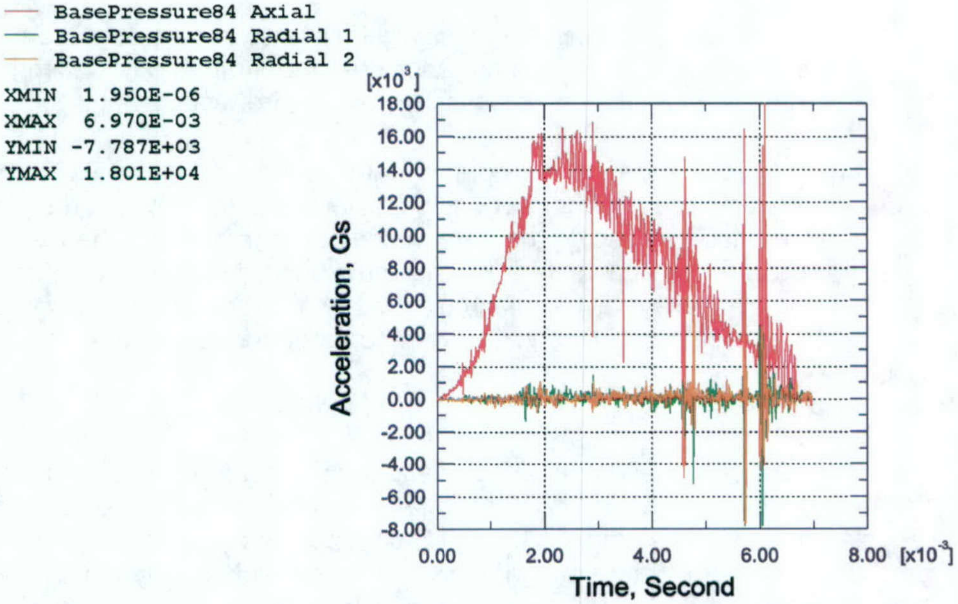

Figure 11
Recorded acceleration, PMP +5%, case BasePress84

Observations

From figures 2 through 11, the following observations can be made:

- The shape of the acceleration curves is similar for each of the shots and consistent with gun shots on other projectiles. Roughly, the axial acceleration curve approximates a (1-cosine) shape.
- There is a change in slope in the axial acceleration before set back, between about 0.001 and 0.002 sec. The axial acceleration is coupled to the transverse acceleration. The coupling prior to set back is clearer in figures 3, 4, 5, 8, and 9. This bump has not been traced to failures in components. The cause of the acceleration bump is under investigation.
- For all of the shots, the set back accelerations include higher-frequency accelerations. The high-frequencies at set back are clearer in figures 3, 5, 6, 10, and 11.
- At set back, the transverse acceleration is relatively low. This was true for all 10 live-firings.
- All of the shots show high-frequency content after set back and prior to muzzle exit. This response correlates to movement of the obturator passing the bore evacuator (ref. 10). For the figures 2 through 5, this occurred at about 0.009-sec.
- The muzzle exit provides the widest variation magnitudes. The muzzle exit accelerations have high-frequency content. Figures 5, 8, and 9 show set forward accelerations exceeding -4000 g's.
- Ringing, or high frequency accelerations, also occurs at muzzle exit (ref. 11). This is evident in all of the live-fire accelerations. A number of failures have been traced to muzzle exit using electronics for break wire tests.
- It is difficult to define the worst dynamic case among the PMP +5% tests. Some of the tests have a higher set back acceleration, some of the tests had a relatively large impulse passing the bore evacuator, and some of the tests had high accelerations at muzzle exit. To simulate the dynamic accelerations on components, several different simulations should be conducted with different dynamic curves. Figures 3, 9, and 11 are recommended for dynamic simulations.

Correlations and Statistics

Table 1 shows the averages, standard deviations, and coefficients of variation for the 10 PMP +5% firings. The maximum values are recorded maxima and do not include curve smoothing. The transverse accelerations are the magnitudes using both perpendicular directions. The breech pressure had the smallest coefficient of variation. The coefficient of variation for the maximum axial g-force was only slightly more than for the pressure. The average maximum transverse acceleration and the minimum axial acceleration occur at muzzle exit.

Table 1
Statistics of PMP +5% tests

Name	Set back		Muzzle exit		Breech pressure (MPa)
	Axial g's (maximum)	Transverse G's	Axial g's (minimum)	Transverse g's (maximum)	
OBR3	13299	144	-3884	2453	367
OBR2	15320	418	-3405	3467	364
BP1a	14759	64	-2866	3881	364
BP1b	15947	60	-5240	5659	369
GS1a	15310	184	-1514	6023	376
OBR4a	14030	190	-3942	3759	
Truck1a-chec	14210	375	-5386	3739	327
Truck1b	14365	375	-7530	4632	367
BasePress85	17263	138	-1332	2046	332
BasePress84	18009	1451	-4088	8475	327
Average	15251.2	339.9	-3918.7	4413.4	388.4
Standard deviation	1474.2	411.0	-1850.4	1891.4	19.8
Coefficient of variation	0.1	1.2	0.47	0.43	0.06
95% confidence value	16114	581	-5001	5520	451
99% confidence value	16566	707	-5569	6100	485
Maximum	18009	1451	-1332	8475	376.0
Minimum	13299	60	-7530	2046	327.0

Table 1 also shows the 95% and 99% confidence value assuming a normal distribution of the column variable. For design purposes, two load cases are considered. The set back load occurs at the maximum axial acceleration. An axial acceleration of 16,566 g's with a transverse acceleration of 707 g's is suggested. The second load case, occurring at muzzle exit, has the maximum transverse acceleration (balloting) and the minimum axial acceleration (set forward). For muzzle exit, the recommended loads, based on the 10-test sample, would be -5569 g's for set forward and 6100 g's for balloting.

Using the Student's t-test, the average values shown in table 1 are consistent with the Excalibur environmental specification: 15800-g's set back, 4052-g's set forward, and 3962-g's balloting. However, since the maxima values are outside of the 99% range, the distribution of acceleration maxima is not a normal distribution.

CONCLUSIONS

Ten permissible maximum pressure plus 5% acceleration sets for Excalibur were presented. The following conclusions were reached:

1. The nature of the curves was similar.
2. The roughness in the curves varied from sample to sample.

3. The muzzle exit loads showed more variations than the set back loads.

4. The coefficient of variation for breech pressure and for maximum axial acceleration are relatively small.

5. The coefficients of variation for maximum transverse acceleration and for minimum axial acceleration are relatively large.

RECOMMENDATIONS

1. For dynamic analysis of components, figures 3, 9, and 11 are recommended for dynamic simulations on components near the on board recorder (OBR).

2. For static analysis, the 99% confidence levels or the extreme values should be used for redesign of components near the OBR. The 99% confidence values are:

    - Set back: Axial acceleration: 16566 g's
      Transverse acceleration: 707 g's

    - Muzzle exit: Axial acceleration: -5569 g's
      Transverse acceleration: 6100 g's

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