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MODELING AND SIMULTION OF ENGRAVING AND GUN LAUNCH OF A 40-mm SENSOR GRENADE

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14. ABSTRACT

The U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, New Jersey is developing an inert 40-mm sensor grenade, which houses an array of sensors and electronic components. This grenade is intended to be fired from a hand-held launcher and once deployed, relay sensor information back to the user. To accomplish this task, the internal electronic components must be structurally housed and guarded from impact induced g-levels. Also, radio transmitting components within the grenade require unimpeded ability to transmit radio frequency signal, thus prohibiting the use of conductive metallic materials in the grenade's design. These unique design requirements create significant challenges for engineers developing the projectile. Throughout the development process, the need to redesign existing components or incorporate completely new components into the system periodically occurs. Before any prototype production or initial testing conducted to determine the performance and survivability of the new component in the operational environment. This technical report details the finite element simulation of, specifically, the grenade pusher (a separate sabot-like component) and the engraving band on the grenade body. The results of the simulation give a prediction of the projectile response during the engraving and gun launch events; as well as an indication of the overall structural integrity of grenade components.

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FIGURES
(continued)

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INTRODUCTION

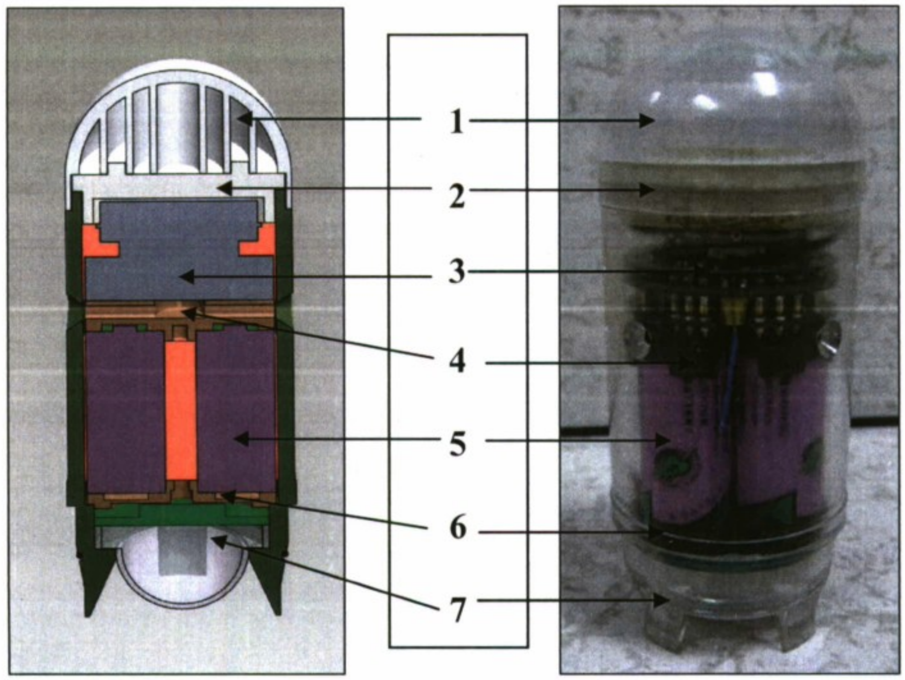
The U.S. Army Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, New Jersey is developing an inert 40-mm sensor grenade that houses an array of sensors and electronic components. This grenade is intended to be fired from a hand-held launcher and once deployed, relay sensory information back to the user. To accomplish this task, the internal electronic components must be structurally housed and guarded from impact induced g-levels. Also, radio transmitting components within the grenade require unimpeded ability to transmit radio frequency (RF) signal, thus prohibiting the use of conductive metallic materials in the grenade's design. These unique design requirements create significant challenges for engineers developing the projectile. Throughout the development process, the need to redesign existing components or incorporate completely new components into the system periodically occurs. Before any prototype production or initial testing of new components is undertaken, finite element simulations are conducted to determine the performance and survivability of the new component in the operational environment. This technical report details the finite element simulation of, specifically, the grenade pusher (a separate sabot-like component) and the engraving band on the grenade body. The results of the simulation give a prediction of the projectile response during the engraving and gun launch events; as well as an indication of the overall structural integrity of grenade components. Previous analysis work done by South, et al (ref. 1) on the engraving/gun launch event was done using quarter symmetric boundary conditions. The analysis work described in this report was modeled in full symmetry and thus resolved all of the physical force components that comprise the engraving and gun launch events.

DESCRIPTION OF SENSOR GRENADE

The sensor projectile is meant to deploy and transmit an assortment of sensory data from its local surroundings back to the user via RF transmission. To accomplish this task, the projectile uses an onboard array of sensors coupled with a stack of printed circuit boards that process and transmit the data. The complete projectile design is shown in figure 1.

The crushable ogive and support disc (section 1 and 2) function to minimize g-levels induced on the remainder of the grenade during an impaction event. The support disc diverts impact forces along the sidewalls of the grenade body rather than directly onto the electronics PCB stack.

The sensor grenade also includes a sensor housed on the rear of the grenade (section 7), which contains a thin, flexible polymeric lens. The lens requires protection from the high gun gas pressures and temperature to function properly once deployed. When exposed to the chamber pressure and temperature, early tests indicated that the lens would collapse and damage the enclosed sensors. Figure 2 shows an example of a collapsed lens that was recovered post firing.



1: Crushable ogive, 2: support disc, 3: PCB stack, 4: Top spacer, 5: battery, 6: bottom spacer,7: rear sensor with polymer lens

Figure 1
Grenade components

Figure 2
Collapsed lens cover

To offer protection against propellant gasses, a pusher component interfaces between the rear of the grenade and propelling charge within the loaded cartridge. The geometry of the pusher is designed in such a way as to seal the internal volume occupied by the rear sensor and diverts the transmission of propulsion forces through the projectile body rather than onto the lens itself. Figure 3 shows the pusher geometry and location in a fully assembled cartridge case.

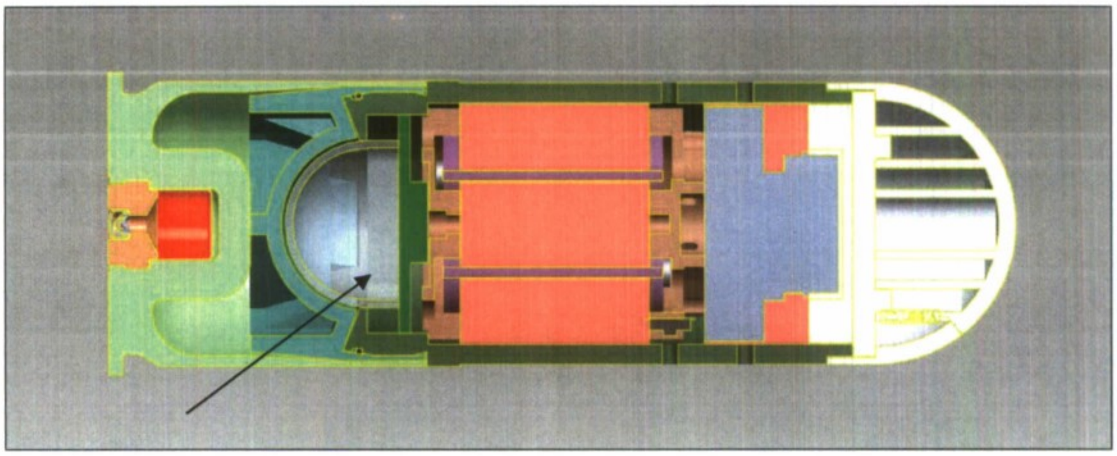


Figure 3
Model of pusher component in fully assembled cartridge

Description of Engraving and Gun Launch Events

The gun launch event begins with the ignition of the propellant charge that is contained within the cartridge case. The propellant rapidly evolves product gasses, which pressurize the chamber and the outside surface of the pusher. The resultant force engages the projectile's drive band into the gun tube rifling of launcher. The tube lands begin to shear and displace material out of the drive band and create a mechanism that imparts rotational velocity on the projectile as it travels further down the gun tube. As the projectile is propelled, there are four primary loads exerted on both the projectile and pusher. These are the pressure loads distributed along the outside of the pusher, the torsional load induced by the drive band acting through the body and into the pusher, and also setback and balloting forces due to the projectile's own inertia and contact interactions with the tube walls.

MODELING AND SIMULATION

The modeling of engraving/gun launch was performed in the ABAQUS Explicit, v6.81, finite element software package. The solid geometry originated in Pro/Engineer Wildfire, v3.0. The finite element analysis detailed in this section will predict the stress levels induced in the pusher and projectile body by the launch induced forces. The criterion for a successful design is one that exhibits minimal plastic deformation, no material failure, and proper spin-up/launch dynamics. In this way, the finite element analysis provides a means of screening design concepts for inadequacy before prototype fabrication and initial testing.

Model Geometry

Sensor Projectile

The sensor projectile is shown a modeled for the analysis in figure 4. A half section view is shown in figure 5 is purely for viewing purposes only. The red portion is the geometry of the body with the green portion representing the internal components of the projectile. As per the assembly procedure, the internal components are encapsulated in an epoxy potting material for added structural support. A simplifying assumption of the analysis is that the innards are represented by a cylindrical puck with the material properties of the potting material. This simplification reduces the mesh size and computation time of the analysis. The cylindrical puck is shown in figure 4 and 5. Also shown in figures 4 and 5 is the support disc (white) with which the crushable ogive (blue) is supported. For material properties of these components, see the Material Properties and Assignments section.

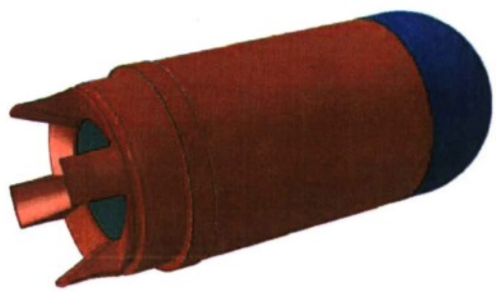


Figure 4
Sensor projectile as modeled in the analysis

Figure 5
Section view of projectile

Pusher

The analysis model also included the pusher part which seals the rear of the sensor projectile from gun gasses and acts to push the projectile down the gun barrel. Figure 6 shows the geometry used in the analysis. Notice that the top portion of the pusher that wraps around the side of the body is absent. This portion does not contribute to the overall structural dynamics of the projectile and when meshed creates very dense and superfluous mesh regions that add unneeded complication and computation time. These features have been removed to minimize computation and complexity.

Figure 6
Pusher component as modeled

A section view of the pusher is shown in figure 7. The pattern of ribbing and cutouts in the pusher are necessary for the injection molding production process in which it is made. A relatively constant cross-section is maintained throughout the part to prevent distortions during molding. Through this design achieves compatibility with injection molding processes, the reduced amount of material creates the possibility of yielding and failure given the interior ballistic load environment. The analysis results will predict whether or not this geometry is structurally adequate.

Figure 7
Section view of pusher as modeled

Gun Tube

The model of the gun is shown in figure 8 as a section view. The tube contains six grooves with a 1:48 twist. The tube was assumed to negligibly deform as the modulus/stiffness of steel is ~35 times the stiffness of the polymer used for the body and was modeled as a rigid body part to minimize computation.

Figure 8
Section view of the gun tube

Material Properties and Assignments

Assignments

Figure 9 and table 1 show the material assignments.

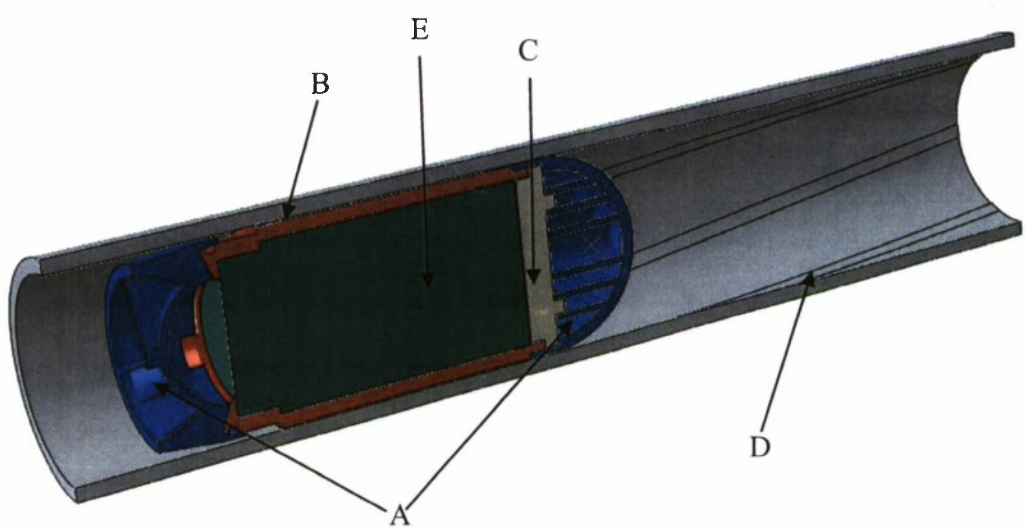


Figure 9
Material assignments

Table 1

Key (color)	Material	Number of instances
A (blue)	Polycarbonate	2
B (red)	Glass filled polycarbonate	1
C (white)	Alumina	1
D (grey)	Analytically rigid parts	1
E (green)	Mass simulant of internals (epoxy potting)	1

Material Properties

For information on material properties used, see appendix A.

Boundary Conditions and Loads

Encastre Boundary Condition

The rigid gun tube was held fixed in all translational and rotational directions using an encastre boundary condition on the tube's rigid body reference node. The arrangement of the reference node is indicated in figure 10.

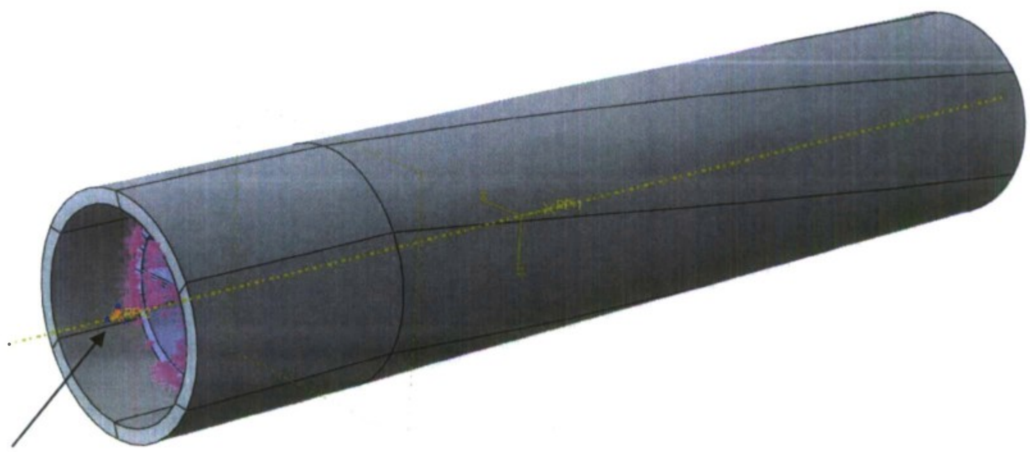


Figure 10
Encastre boundary condition

Pressure Load and Applied Amplitude

The pressure load was applied to the outer rearward surfaces of the pusher as shown in red in figure 11.

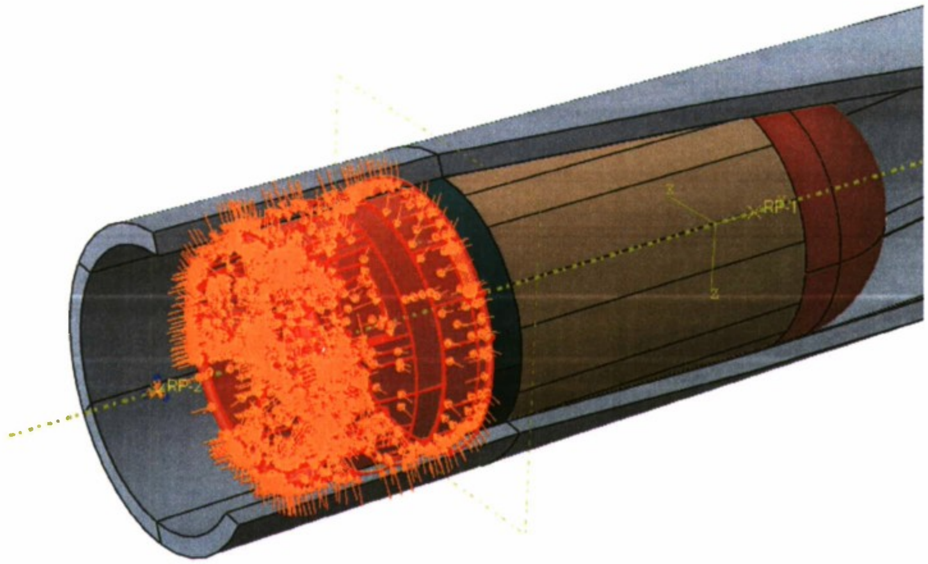


Figure 11
Surfaces with applied pressure load

The magnitude of the pressure load varies throughout the duration of the analysis as would occur in actual live firing. The pressure loading curve is shown in figure 12. This pressure time curve was generated from experimental data of a similar 40-mm grenade and then was scaled to a peak pressure that corresponds to the pressure required for firing of this projectile.

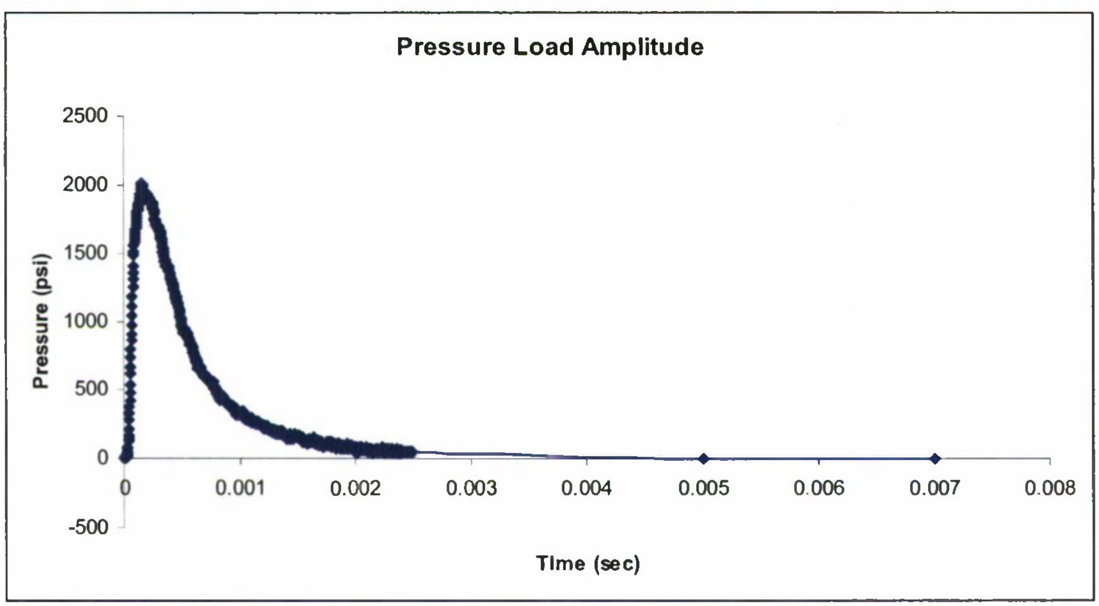


Figure 12
Pressure load

SIMULATION RESULTS

Engraving Result

The engraving results from the analysis compared to live fire testing are displayed in figures 13 and 14. The resulting geometries match very closely.

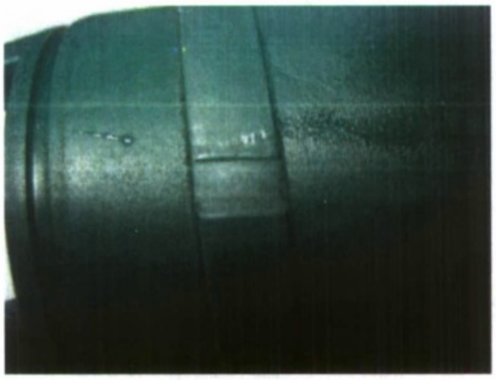


Figure 13
Analysis: engraved rive band

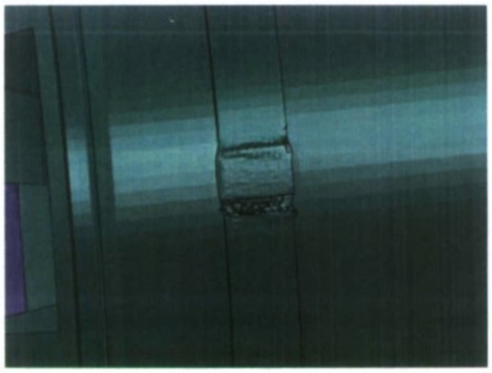


Figure 14
Test: engraved drive band taken August 2008

Pusher Plastic Deformation Result

The end state of the pusher shows small areas of plastic deformation (fig. 15), mainly at inside corner locations where sharp geometry causes stress concentration. The plastic strains do not extend significantly through the thickness of the side walls and are relegated to relatively few areas on the part. These results indicate no structural deficiency in the design part.

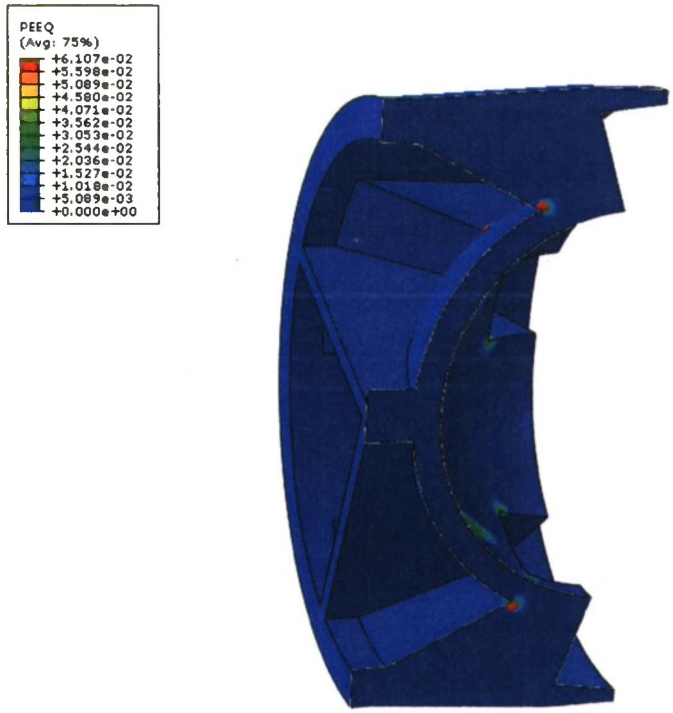


Figure 15
Plastic strain distribution in the pusher

Live Fire Testing

Live fire testing of this design was conducted at ARDEC at the Armament Technology Facility in August 2008. A total of 10 shots were fired from an equivalent gun tube to verify the pusher survivability and drive band performance. The configuration was consistent with that of the finite element analysis. A still image from high speed video is shown in figure 16 from the test. All 10 shots exhibited the same drive band wear (fig. 14) and pusher survival as predicted by the model.

Figure 16
High speed photograph at muzzle exit during live fire test

DISCUSSION

The analysis shows that the drive band on the body of the projectile will impart spin without exhibiting "wiping." Wiping is a term used to describe a situation where the band fails in shear mode and the grooves of the gun tube are unable to impart significant rotational velocity onto the projectile. The analysis model did not predict this phenomenon and confirmed the suitability of glass filled polycarbonate material for the sensor grenade application. Live fire testing also confirmed the model prediction. High speed video taken at muzzle exit indicated proper rotational velocity like that shown in figure 16.

In addition, the material selection and design of the pusher component were validated by the analysis model. The results of live fire testing showed negligible plastic deformation and showed 100% survival and lens protection thus indicating a successful design. The regions of yielding predicted in the model (fig. 15) are highly unlikely to cause the part to fail as they are small in size and magnitude. Furthermore, the inside corners on the part as it is manufactured have a radius applied to them that theoretically mitigates the stress concentration effect.

REFERENCES

1. South, Joseph; Powers, Brian; and Brant, Andrew, "Numerical Engraving and Obturation Analysis of the M433 Projectile Launched from the M203 Barrel," U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, January 2008.

APPENDIX A
SENSOR GRENADE DETAILS

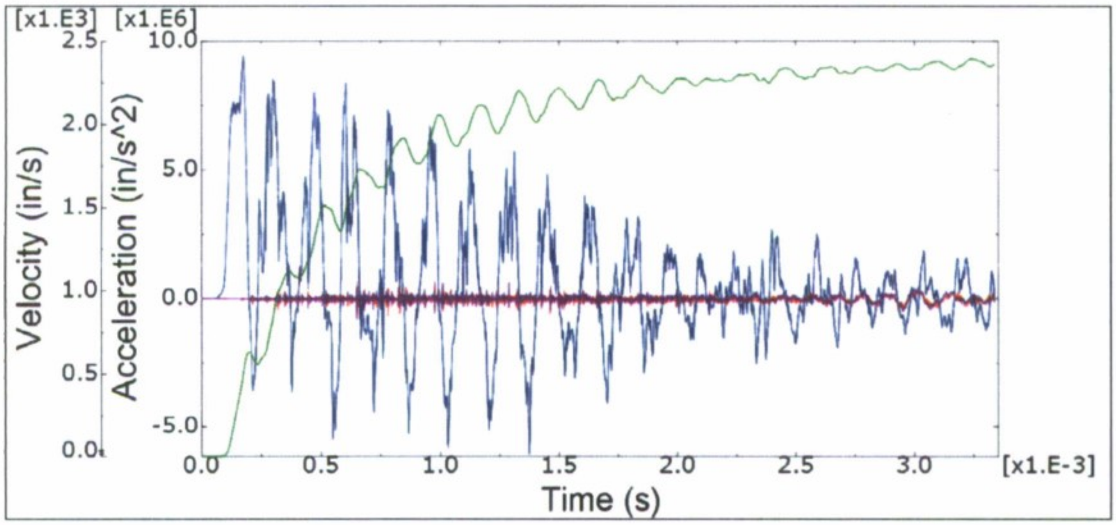
Material Properties

	Density $\left(\frac{1fb \cdot s^2}{in.^4}\right)$	Modulus of elasticity (psi)	Poisson's ratio	Yield strength (psi)
Polycarbonate, unfilled[a]	0.000111	350,000	0.37	11,000
Polycarbonate, glass filled[a]	0.000127	79,9000	0.32	16,500
Alumina	0.000344	40,000,000	0.22	
Epoxy potting[a]	0.000161	151,963	0.4	1,900

[a]Johnson-Cook plasticity material model was used for this material definition. The parameters are proprietary to the U.S. Department of Defense.

APPENDIX B
MODEL OUTPUTS

Plot displays nodal output taken from a reference point at the base of the support disc.



Legend

A1 PI: rootAssembly N: 1 NSET SET-DISK-RP
A2 PI: rootAssembly N: 1 NSET SET-DISK-RP
A3 PI: rootAssembly N: 1 NSET SET-DISK-RP
V2 PI: rootAssembly N: 1 NSET SET-DISK-RP

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