Modeling and Simulation of Engraving and Gun Launch of a 40mm Sensor Grenade

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Abstract: The U.S. Army Armament Research, Development and Engineering Center (ARDEC) at Picatinny Arsenal, NJ is developing an inert 40mm sensor grenade which houses an array of sensors and electronic components. This grenade is intended to be fired from a hand held launcher and 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 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. Component designs had to be screened for performance and survivability before costly prototypes were fabricated. Abaqus Explicit was used to analyze the grenade during gun launch and engraving events and predict projectile performance. The 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. Analysis results of the engraving pattern are compared with actual recovered live fire grenades.

Keywords: grenades, Sensors, Impact, Dynamic, Response, 40 mm, engraving, gun launch

1. 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 which process and transmit the data. The complete projectile design is shown in Figure 1.

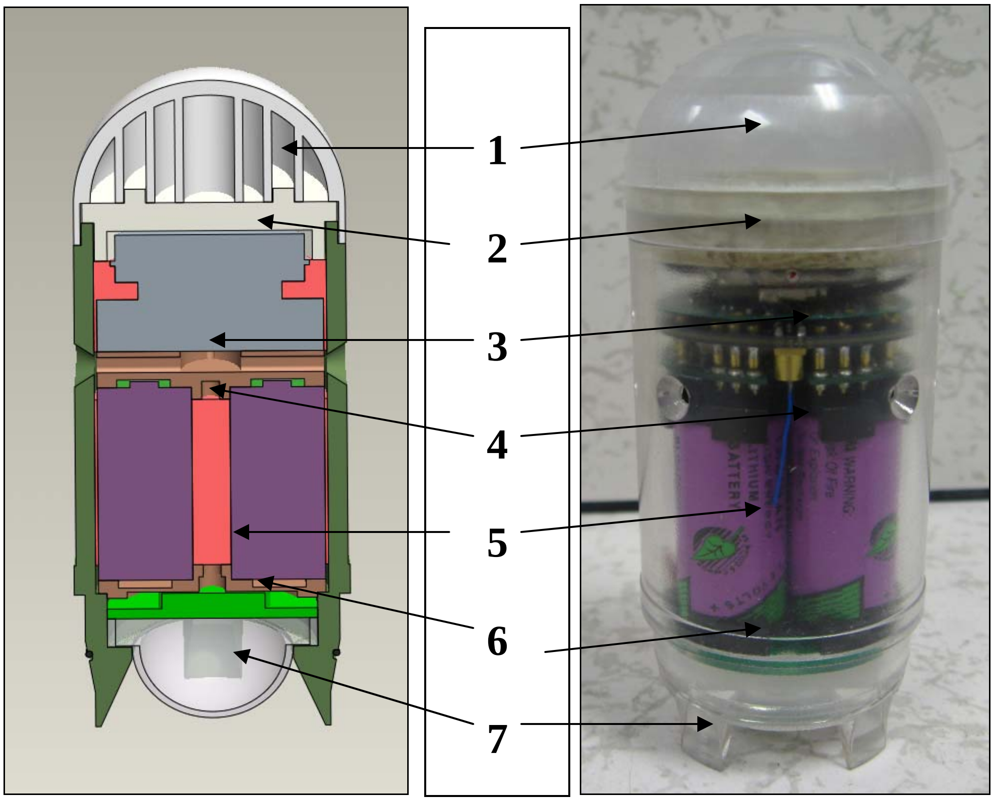

Figure 1. Grenade Components

Crushable O-give, 2: Support Disc, 3: PCB Stack, 4: Top Spacer, 5: Battery, 6: Bottom Spacer, 7: Rear Sensor with Polymer Lens

The crushable ogive and support disc (sections 1 & 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.

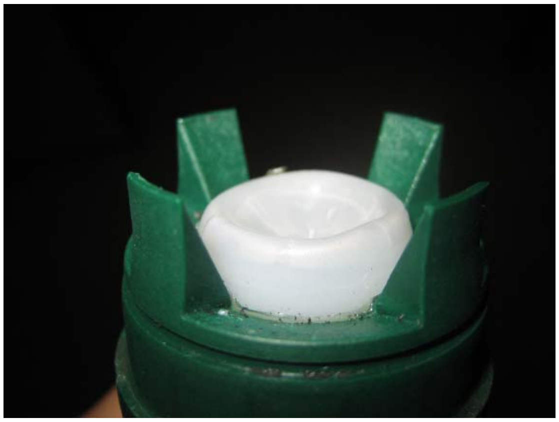

Figure 2. Collapsed lens cover

To offer protection against propellant gasses, a pusher component interfaces between the rear of the grenade and the 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.

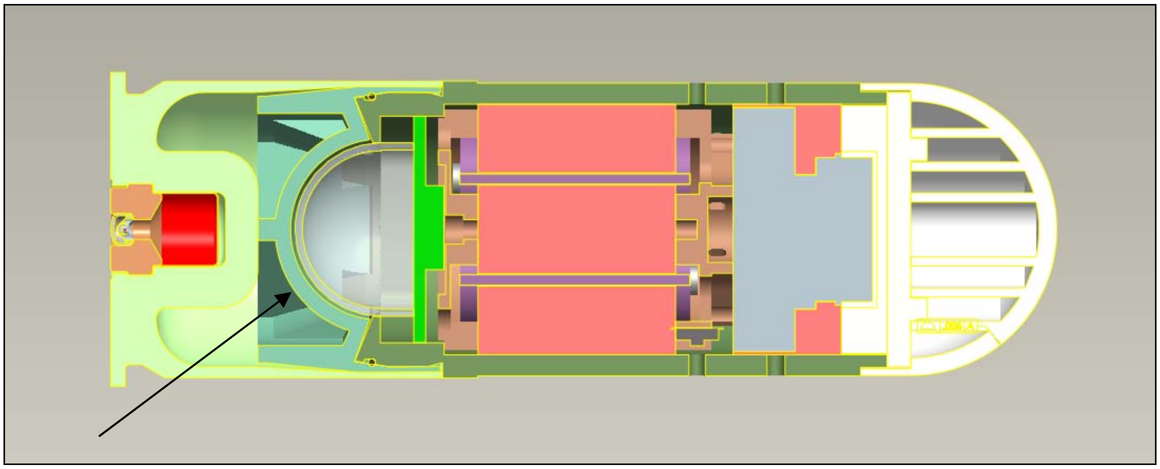

Figure 3. Model of pusher component in fully assembled cartridge.

1.1. Description of Engraving and Gun Launch Events

The gun launch event begins with the ignition of the propellant charge which 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 which imparts rotational velocity on the projectile as it travels further down the gun tube. As the projectile is propelled, there are 4 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.

2. 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 which 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.

2.1. Model Geometry

2.1.1. Sensor Projectile

The sensor projectile is shown as modeled for the analysis in Figure 4. A half section view is shown in Figure 5. Note this is a full symmetric model; the section 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 Figures 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 section 2.2.

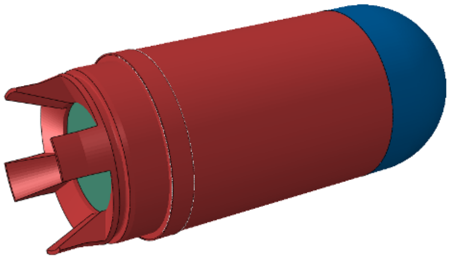

Figure 4. Sensor projectile as modeled in the analysis

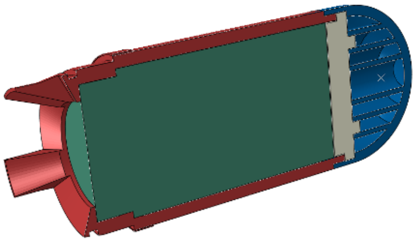

Figure 5. Section View of projectile

2.1.2. 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. See Figure 6 which 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 cut-outs 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. Though 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

2.1.3. Gun Tube

The model of the gun tube 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

2.2. Material Properties and Assignments

2.2.1. Assignments

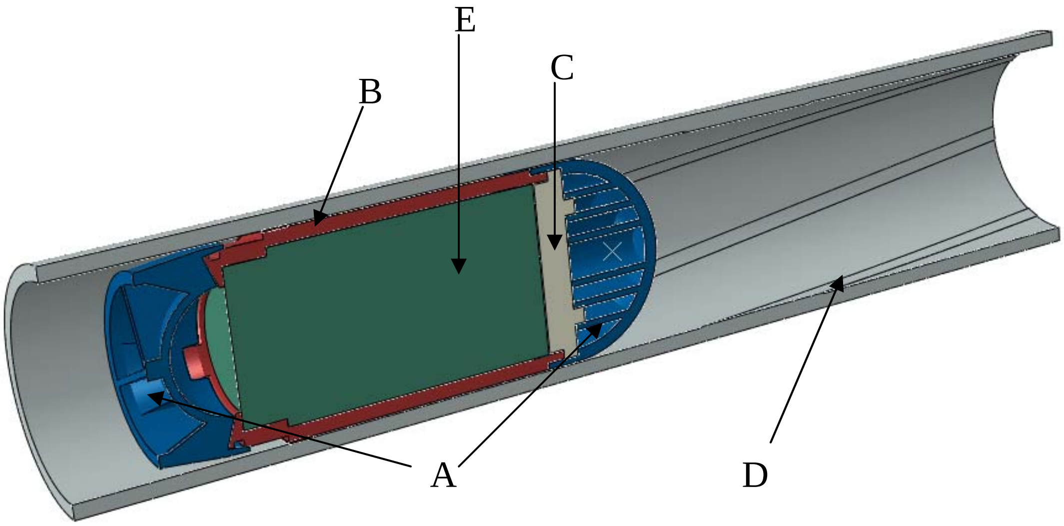

Figure 9. Material assignments

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

Table 1. Material assignment key

2.2.2. Material Properties

For information on material properties used, see Appendix A: Sensor Grenade Details.

2.3. Boundary Conditions and Loads

2.3.1. 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.

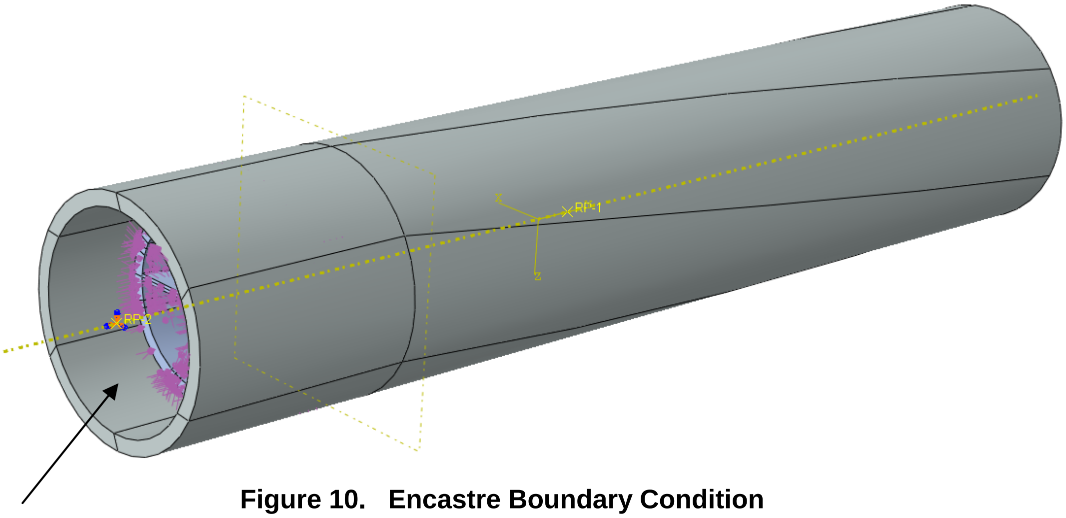

Figure 10. Encastre Boundary Condition

4.3.2 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.

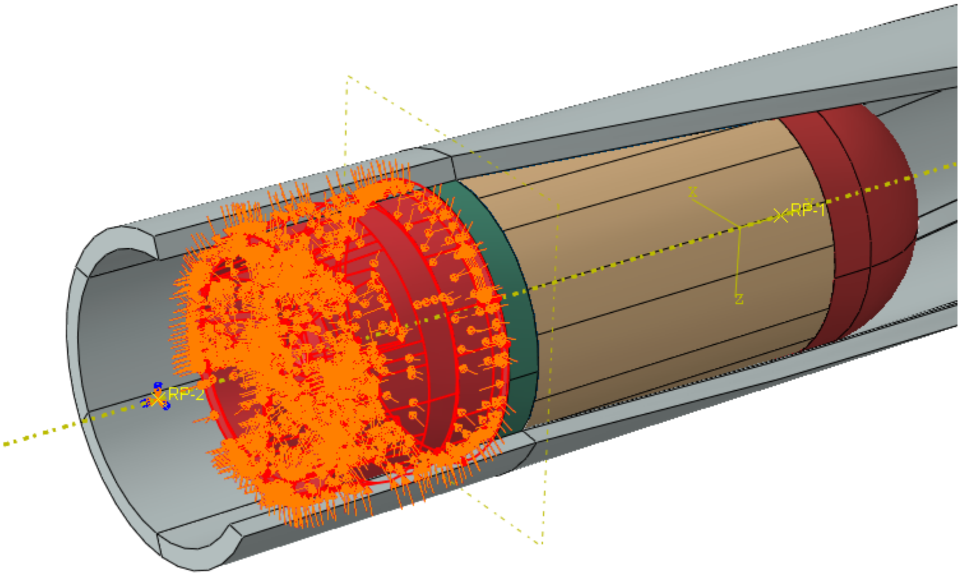

Figure 11. Surfaces with applied pressure load

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 40mm grenade and then was scaled to a peak pressure that corresponds to the pressure required for firing of this projectile.

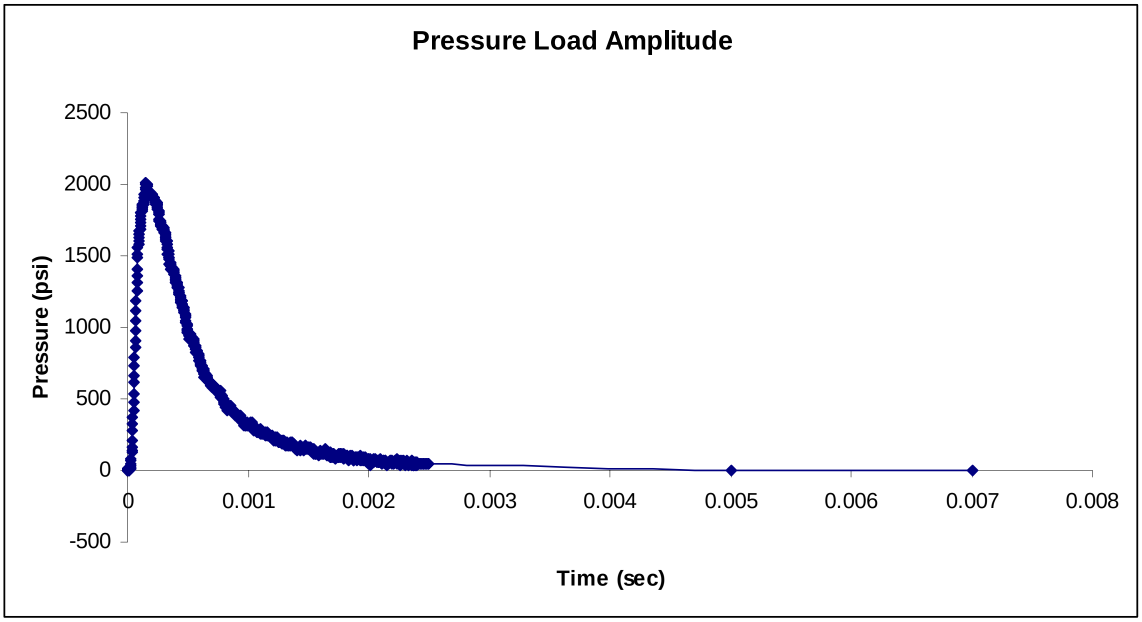

Figure 12. Pressure load

3. Simulation Results

3.1. Engraving Result

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

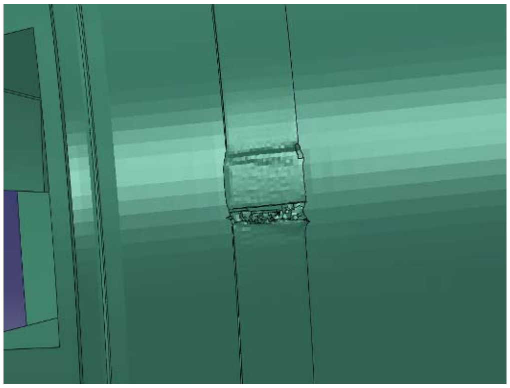

Figure 13. (Left) Analysis: Engraved drive band

Figure 14. (Right) Test: Engraved drive band taken August 2008.

3.2. Pusher Plastic Deformation Result

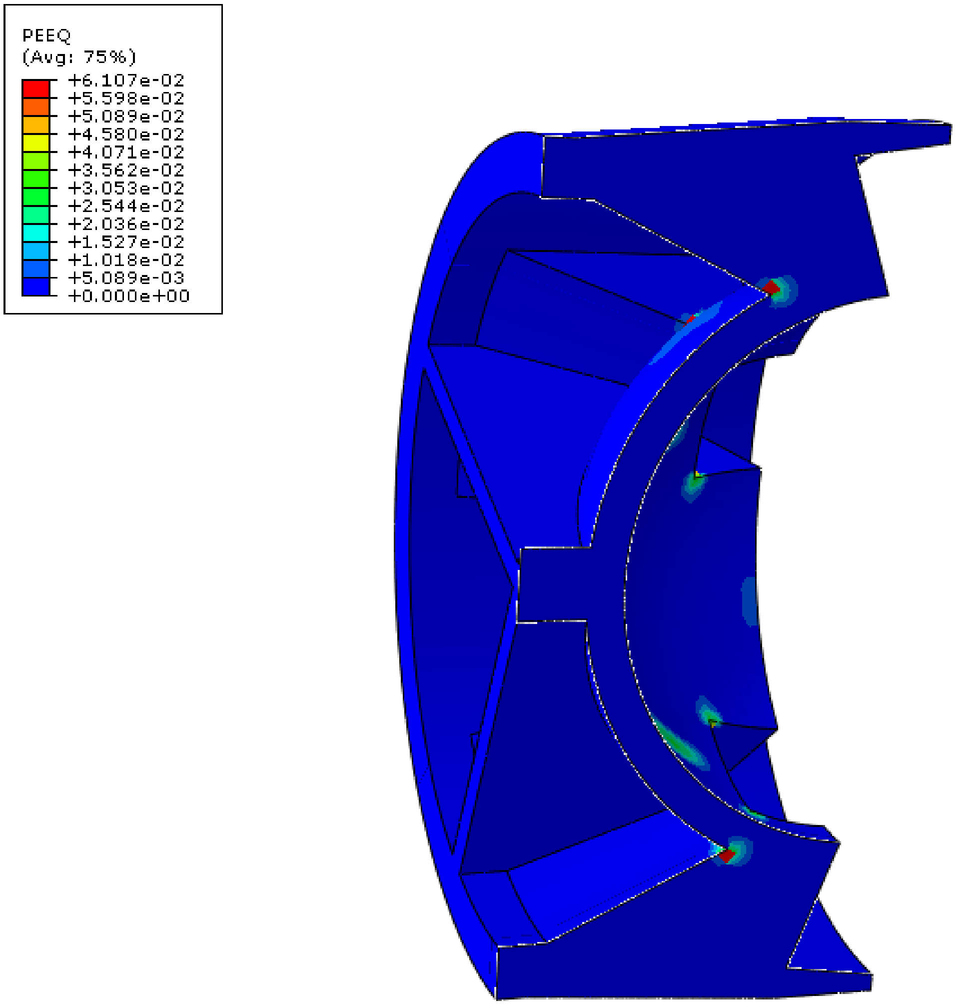

Figure 15. Plastic strain distribution in the pusher

The end state of the pusher shows small areas of plastic deformation, 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 of the part.

3.3. Live Fire Testing

Live fire testing of this design was conducted at Picatinny Arsenal, NJ at the Armament Technology Facility in August 2008. A total of 10 shots of 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 (see Figure 14) and pusher survival as predicted by the model.

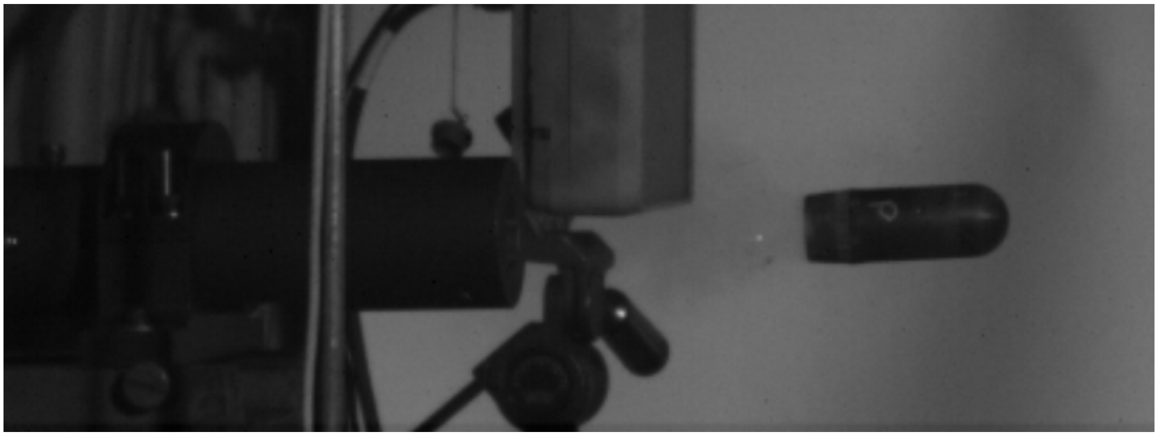

Figure 16. High speed photo at muzzle exit during live fire test

4. 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 (refer to Figure 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 which theoretically mitigates the stress concentration effect.

References

1. South, Joseph; Powers, Brian; 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.

2. Recchia, S.; Geissler, D.; Maselli, M; Tabao, D. Technical Report ARAET-TR-07011 Improving the Reliability of the M782 MOFA 155-mm Artillery Fuze; US Army Armament Research, Development, and Engineering Center, June 2007.
3.

Appendix A: Sensor Grenade Details

Table 2. Material Properties

	Density $\frac{\text{lfb s}^2}{\text{in}^4}$	**Modulus of Elasticity (psi)**	**Poisson's Ratio**	**Yield Strength (psi)**
Polycarbonate, Unfilled[1]	0.000111	350000	0.37	11000
Polycarbonate, Glass Filled[2]	0.000127	799000	0.32	16500
Alumina	0.000344	40000000	0.22	
Epoxy Potting[3]	0.000161	151963	0.4	1900

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

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

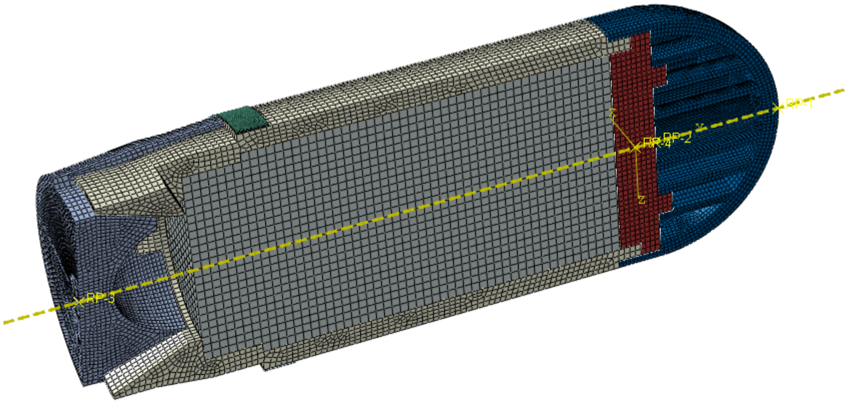
[3] Johnson-Cook plasticity material model was used for this material definition. The parameters are proprietary to the U.S. Department of Defense.

Appendix B: Mesh Information

Total Number of Nodes: 601864

Total Number of Elements: 486437

Element Type: CD38R



Section View of Projectile Mesh

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