AD

AD-E403 372

Technical Report ARMET-TR-11033

120-mm MORTAR FUZE REDUCED THREAD GUN LAUNCH SURVIVABILITY

R. Terhune
J. A. Cordes
S. DeFisher
R. Wong

January 2012

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Munitions Engineering Technology Center

Picatinny Arsenal, New Jersey

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-01-0188*

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (*From - To)*
January 2012	Final	December 2010 to June 2011

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
120-mm MORTAR FUZE REDUCED THREAD GUN LAUNCH SURVIVABILITY	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHORS	5d. PROJECT NUMBER
R. Terhune, J.A. Cordes, S. DeFisher, and R. Wong	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army ARDEC, METC Fuze & Precision Armament Technology Directorate/Munitions Systems and Technology Directorate (RDAR-MEF-E/MEM-A) Picatinny Arsenal, NJ 07806-5000	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army ARDEC, ESIC Knowledge & Process Management (RDAR-EIK) Picatinny Arsenal, NJ 07806-5000	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S) Technical Report ARMET-TR-11033

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

A finite element analysis study was completed on the forward joint of a 120-mm mortar. The purpose of the study was to determine to what degree the adapter threads could be diametrically interrupted without compromising structural integrity during gun launch. The finite element analysis modeled the mortar assembly with a dynamic pressure load. Material nonlinearities were included in the analysis. Contact surfaces in the joint were modeled as threads. The results of the analysis indicated that four circumferential slots could be cut into the joint. For the given gun launch pressure, slots amounting to about 56% of the circumference did not result in stresses exceeding the yield strength of the joint.

15. SUBJECT TERMS

120 mm Mortar Slow cook off (SCO) Gun launch Finite element analysis (FEA) Fuze

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			R. Terhune
U	U	U	SAR	21	19b. TELEPHONE NUMBER (Include area code) (973) 724-1383

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

CONTENTS

FIGURES

FIGURES
(continued)

ACKNOWLEDGMENTS

The authors of the report wish to thank the following engineers for the many helpful comments and suggestions: Jackie Longcore for pressure load data and Ryan Hooke for material data.

INTRODUCTION AND BACKGROUND

A finite element analyses (FEA) study was completed on the forward joint of a 120-mm mortar. The purpose of the study was to determine if threads could be reduced circumferentially without compromising structural integrity during gun-launch. The finite element model was nonlinear and dynamic. A range of slot geometries were investigated. The results of the analysis indicated that four diametric slots could be cut into the joint. For the given gun-launch pressure, four 0.95-in. slots could be cut into the joint without affecting the integrity of the joint during gun launch. Slot length predictions were based on applied pressure-time curves. Torsional and balloting effects were not included in the study.

The direct impetus for conducting this study was the need to improve the insensitive munitions (IM) performance of the 120-mm high explosive (HE) round when it is subjected to a slow cook-off (SCO) threat. In order for a HE munition, subjected to any one of a number of tests designed to simulate those commonly found on the battlefield, to behave in a manner that is less violent than when it is functioned as intended, various IM features need to be incorporated into the overall design. These features typically include more IM compliant explosive fills, packaging modifications, and warhead venting features to name just a few. One of the problems with implementing IM design features is the deleterious effect that it often has on performance or other basic requirements such as the ability to safely gun launch a projectile. In the process of opening diametric channels in the 120-mm mortar fuze adapter and inserting a meltable plastic gasket, IM performance was enhanced, but so was the danger that the round itself would not survive gun launch intact due to the reduced amount of threads and thread engagement, which would be required to bear the load resulting from accelerating the projectile several thousand times the acceleration of gravity. This analysis was an attempt to ensure that the 120-mm HE round would survive launch after the IM enhancing adapter vents were incorporated into the overall design.

FINITE ELEMENT ANALYSES SUPPORTING OTHER ISSUES

Several other technical reports are available regarding modeling and simulation of mortars. Cordes et al. (ref. 1) evaluated broke parts of 120-mm mortar fin booms. Two proximal causes of failure were hypothesized. First, the press fit of the fin hubs onto the shell could result in fracture if a defect was present. Second, failures may also have occurred due to unequal pressure on one side of the fin. Subsequent tests were conducted at Penn State University to determine if the mortar fin had equal pressure on both sides. The Penn State test validated the failure hypothesis. Pressure sensors recorded transient, un-axisymmetric, pressures on different sides of the fins. The transient differential reached about 1000-psi early in the ballistic cycle (ref. 2).

In another root cause investigation (ref. 3), modeling and simulation was used to investigate the causes of a failed mortar body during a lot acceptance test. The mortar body 'peeled' off of the fin boom. The finite element study indicated a relatively large amount of plasticity at the press-fit region between the body and the fin boom. Numerous live mortar tests were subsequently run with various charges and under different environment conditions. For this failure, the proximal cause was not found using modeling and simulation.

In another study, Cordes and others (ref. 4) determined the probability of failure when a defect was present in a 60-mm shell body. The investigation included statistical analysis and modeling and simulation. The study predicted less than one in a million failures and the full production round was used without incident.

Jablonski et al. (ref. 5) determined the critical defect size in 81-mm mortar parts. The analysis required modeling and simulation and linear elastic fracture mechanics.

METHOD, CURRENT STUDY

Like most of the previous mortar studies, the current study used dynamic modeling and simulation. The purpose of the study was to determine the minimum circumferential thread bite for a forward mortar joint. Circumferential gaps in the threads were proposed as a means to mitigate the risk of a SCO failure. Gaps provide pressure relief. Modeling and simulation was used to determine how much circumferential thread was required to maintain structural integrity during gun launch. The general-purpose finite element program ABAQUS Explicit 6.10.EF1 (ref. 6) was used. The models were non-linear and dynamic.

GEOMETRY

Figure 1 shows the geometry of the mortar assembly. The model included a fuze adapter, a gasket, the warhead body, HE fill, the M31 mortar boom, and the M31 mortar fins. The threads between the warhead body and the fuze adapter were modeled as circumferential ribs and not helical swept threads. A point mass replaced the fuze components.

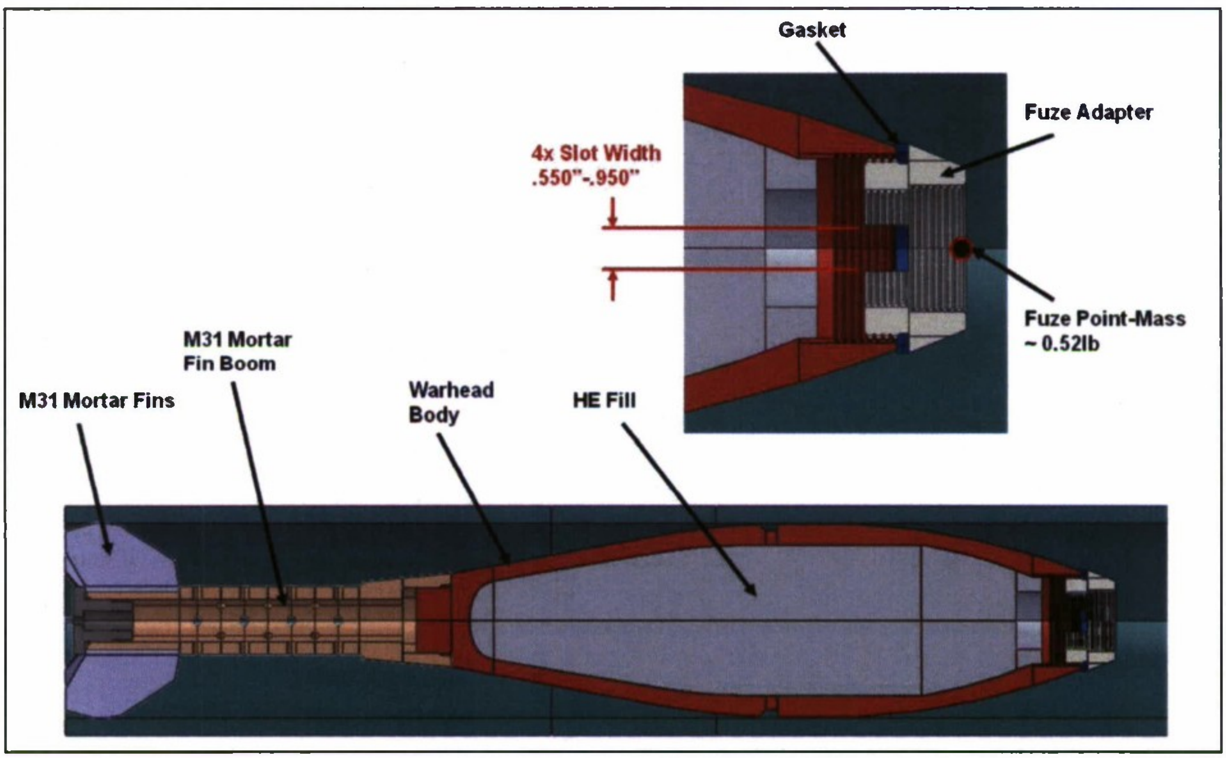

Figure 1
M933 120-mm mortar with modified fuze adapter and fuze point mass

FINITE ELEMENT MESH

The finite element mesh is displayed in figure 2. There are 134,874 elements in total in the model consisting of 120,350 8-node hexahedral elements and 14,524 4-node tetrahedral elements. Although some 4-node tetrahedrals were used, which are less precise, they were used in non-critical areas away from the regions of interest. In the region of concern, the threaded interface, the mesh was refined.

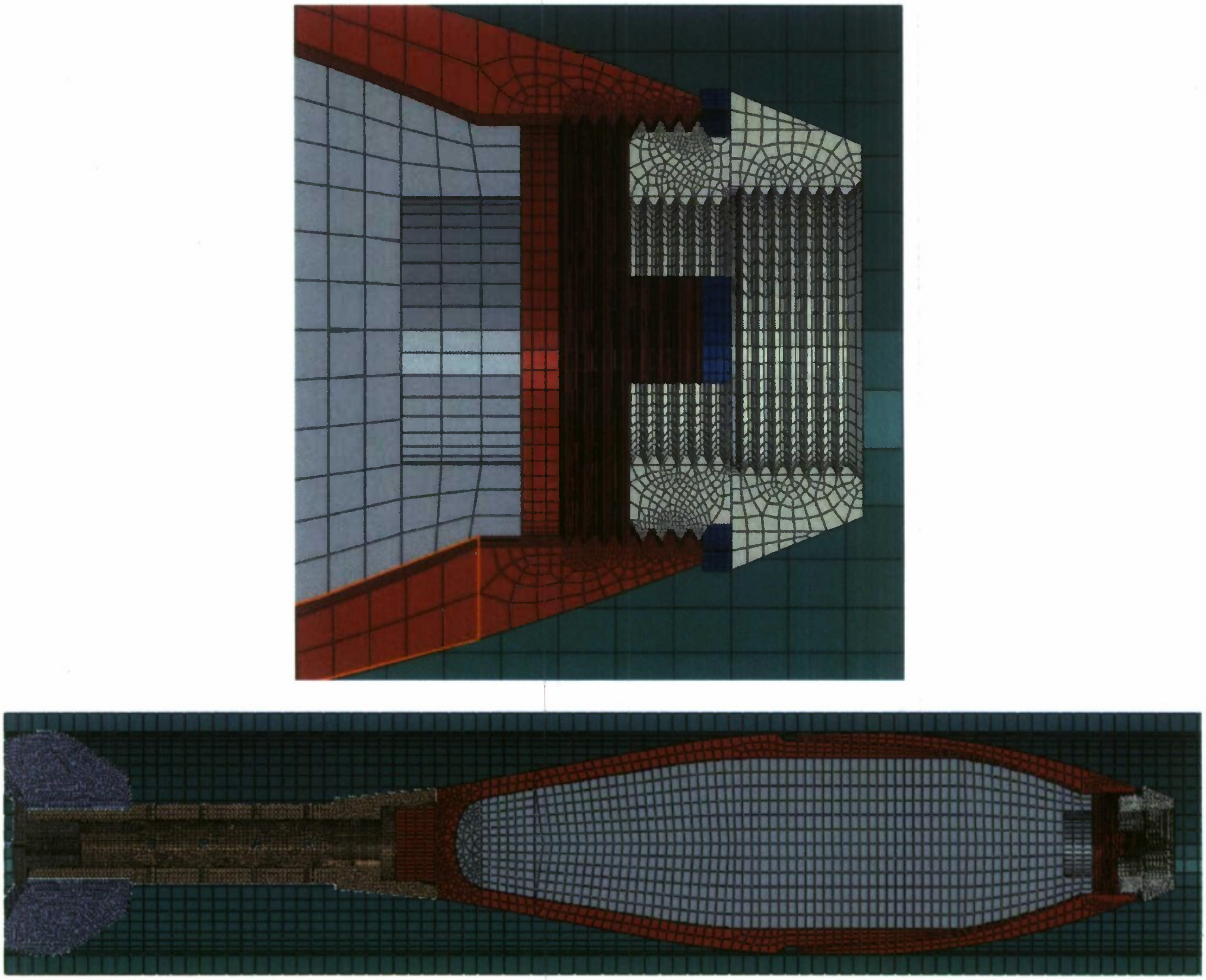

Figure 2
Mortar finite element mesh

MATERIALS

The model used elastic-plastic material models. Material properties were taken from the MIL Handbook (ref. 7) or from Matweb (ref. 8).

Part	Material	Modulus (psi)	Poisson Ratio	Density (lbf*s^2/in^4)	Yield (psi)	Ultimate True Plastic Strain	Ultimate True Stress (psi)
Fuze Adapter	Steel A108, Grade 1117	3.0E+7	0.29	.000732	58,112	0.188	84,700
Gasket	FI 388	33000	0.40	.0001187	600	0.050	5,510
M31 Fin	Al 7075-T6	1.03E+7	0.33	.000261	66,423	0.060	82,390
M31 Fin Boom	Al 7075-T6	1.03E+7	0.33	.000261	66,423	0.060	82,390
Warhead Body	HF1	2.987E+7	0.294	.000727	180,000	0.100	200,000
HE Fill	Comp B	630000	0.34	.000158	3,030	0.530	3,050
Gun Tube (Rigid)	Steel						

APPLIED CONSTRAINTS

Figure 3 summarizes the internal constraint assumptions. General frictionless contact is applied to the entire model at all contacting surfaces as a default. Tied constraints were used between the 1) mortar fins and mortar fin boom and 2) the mortar fin boom and the warhead body. A coupling constraint fixes the fuze point-mass to the fuze adapter. A rigid body constraint is applied to the gun tube.

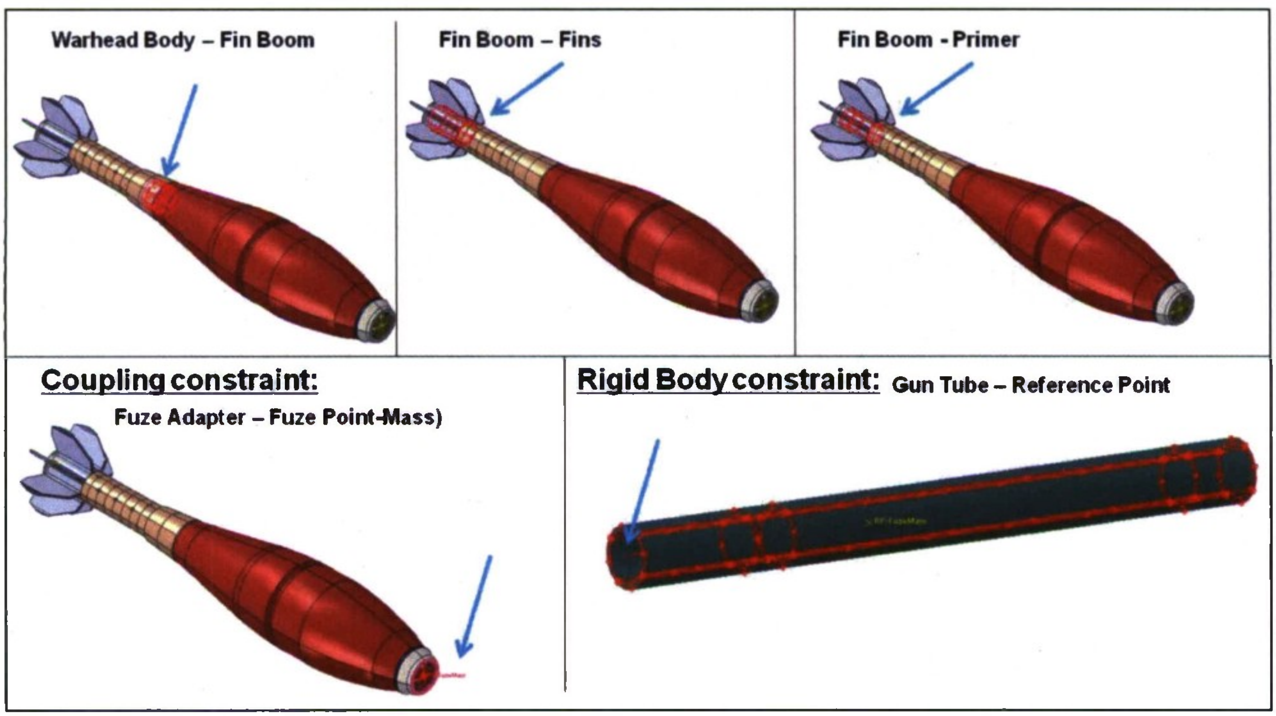

Figure 3
Tie, coupling, and rigid body constraints between various parts of the assembly

APPLIED LOADS AND BOUNDARY CONDITIONS

The zone 4 hot charge pressure loads for this FEA model were provided by Jackie Longcore of the U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, New Jersey. The P-t curve is displayed in figure 4 and is applied to the surfaces of the mortar projectile as seen in figure 5. An encastre boundary condition is applied to the rigid body reference point for the gun tube so it remains fixed through the analysis constraining the mortar round's lateral movement (fig. 6).

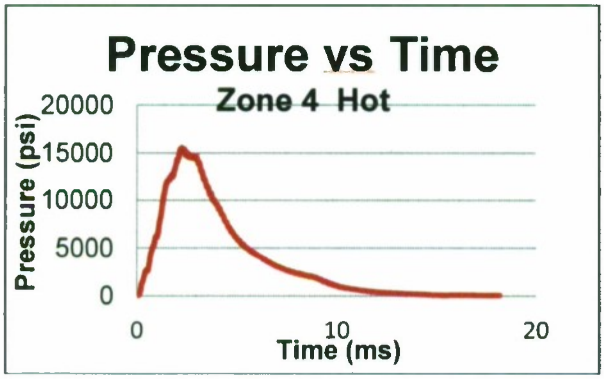

Figure 4
Pressure versus time curve for zone 4 hot charge

Figure 5
Pressure load applied region

Figure 6
Encastre boundary condition applied to rigid body reference point to fix the gun tube

RESULTS

The analysis converged to a solution. At the time of peek base pressure the stresses in the fuze adapter are the largest. The Von Mises stress contour plots displaying the results are in figures 7 to 17. For fuze adapter slot widths up to 0.950 in. the fuze adapter will survive gun launch under the given assumptions. With the 0.95-in. slot, the maximum stress in the analysis reached 52,000 psi, less than the assumed value of 58,112 psi for the yield strength. The load path changes with the addition of a gasket between the warhead body and fuze adapter. The gasket will compress taking some of the setback load and the threads of the fuze adapter will also share the load as opposed to a standard flush mounted fuze adapter. The 0.95-in. length slots account for 56% of the circumferential thread length. As seen in figure 8, the gasket was also examined and it will yield in certain locations, but will not have complete failure; thus surviving gun launch marginally. The gasket stress did not vary much with the fuze adapter slot width.

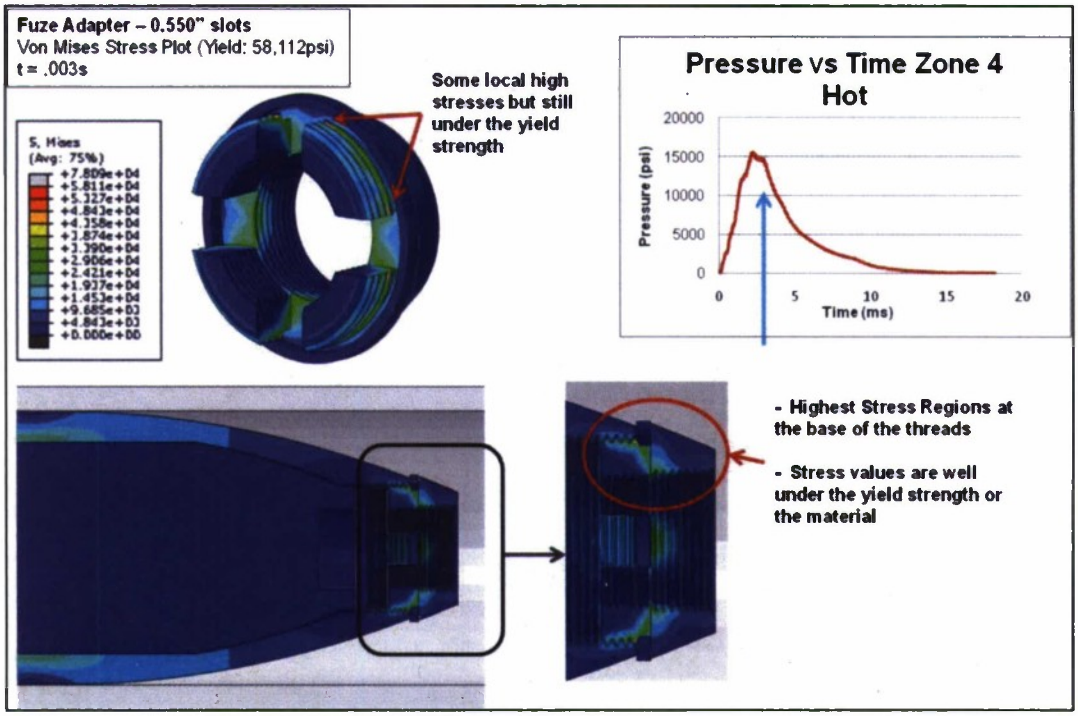

Figure 7
Von Mises stress contour plots of the fuze adapter with 0.550-in. slots at t = 0.003s

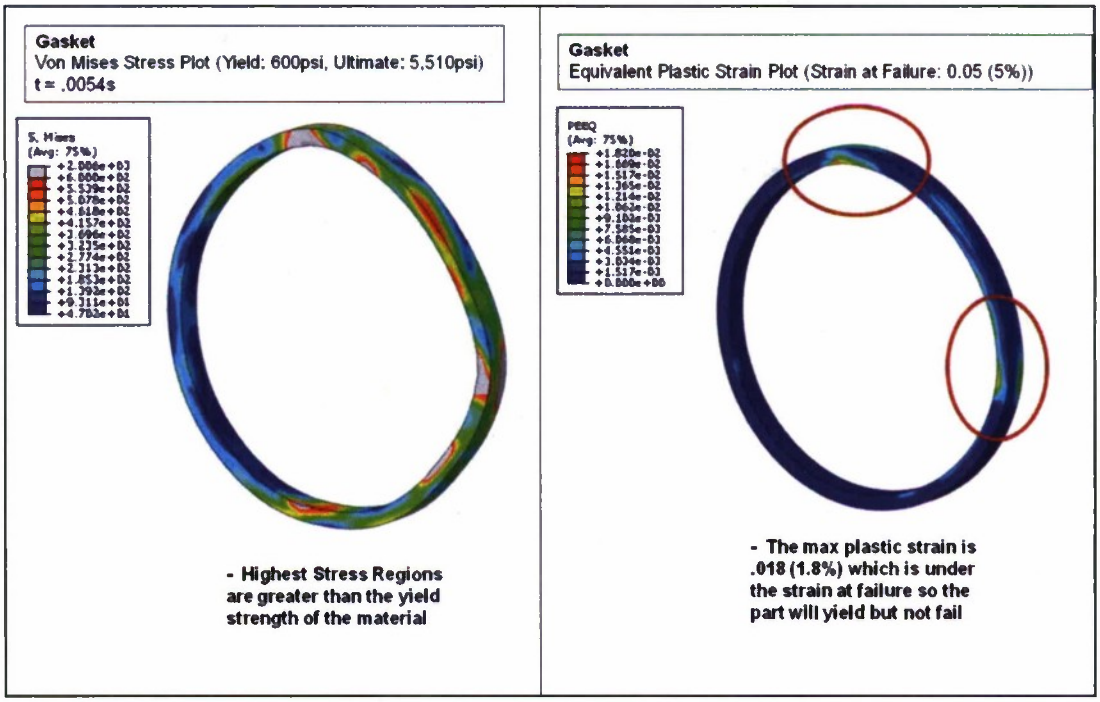

Figure 8
Von Mises Stress contour plot and equivalent plastic strain contour plot

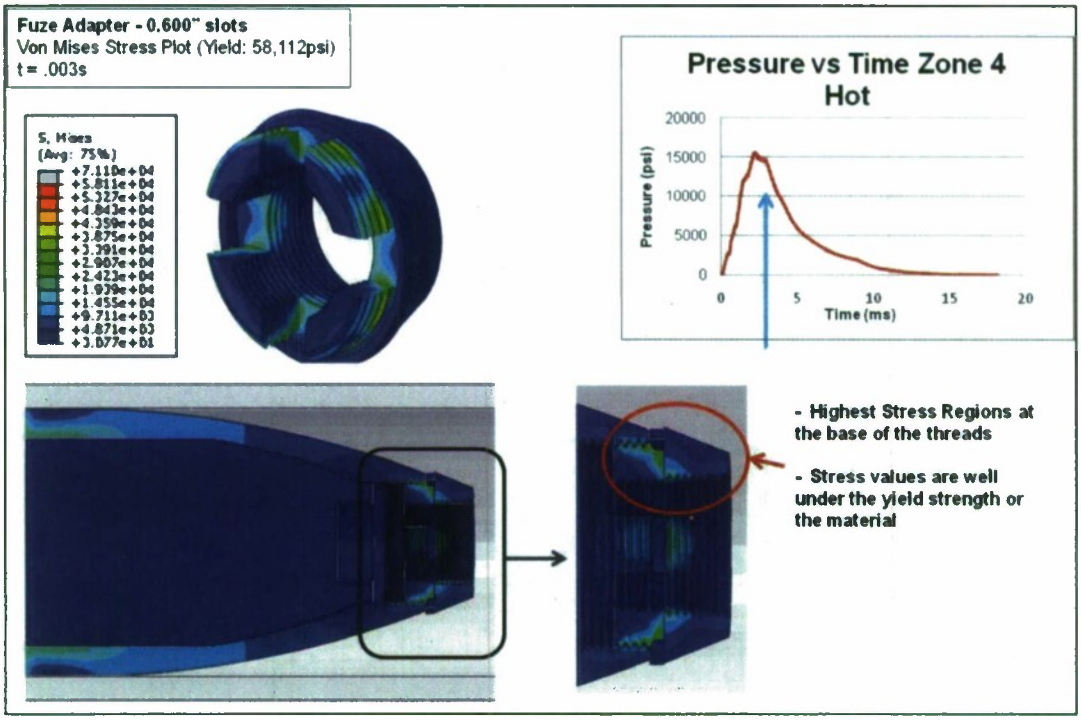

Figure 9
Von Mises stress contour plots of the fuze adapter with 0.600-in. slots at t = 0.003s

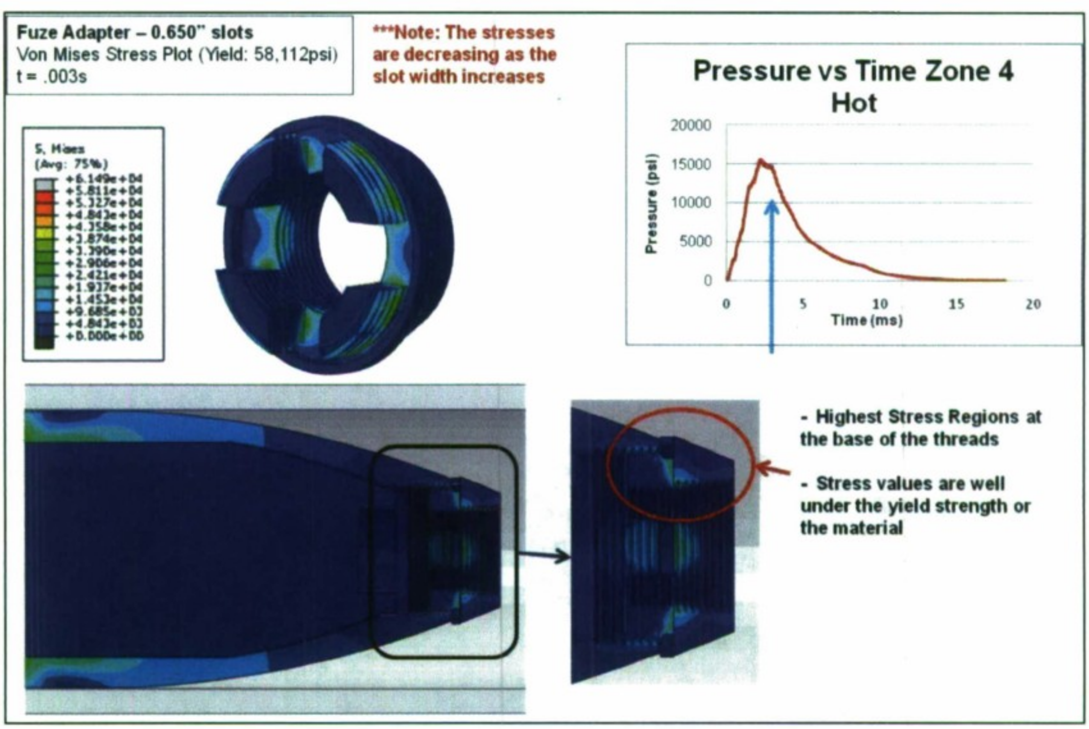

Figure 10
Von Mises stress contour plots of the fuze adapter with 0.650-in. slots at t = 0.003s

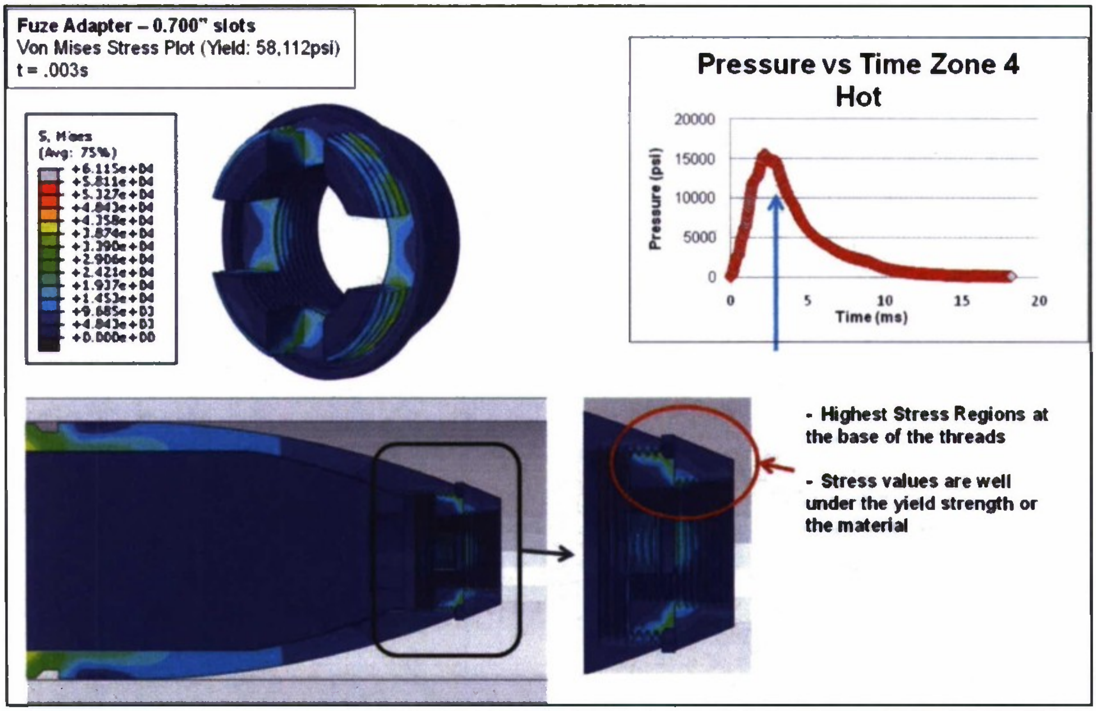

Figure 11
Von Mises stress contour plots of the fuze adapter with 0.700-in. slots at t = 0.003s

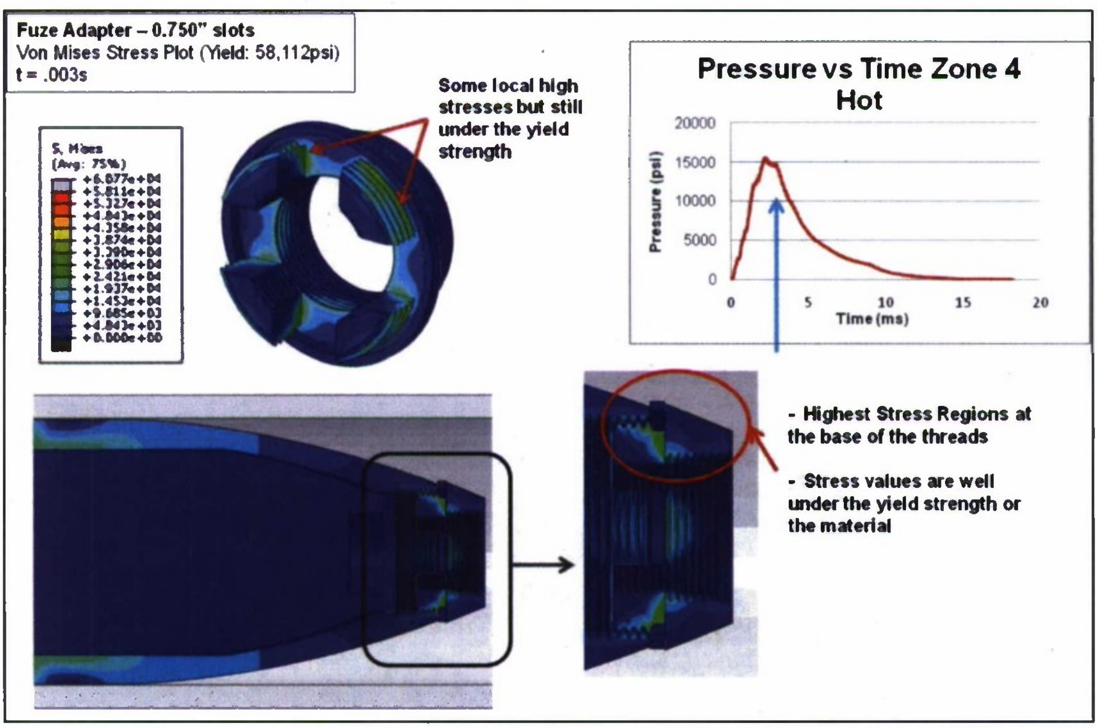

Figure 12
Von Mises stress contour plots of the fuze adapter with 0.750-in. slots at t = 0.003s

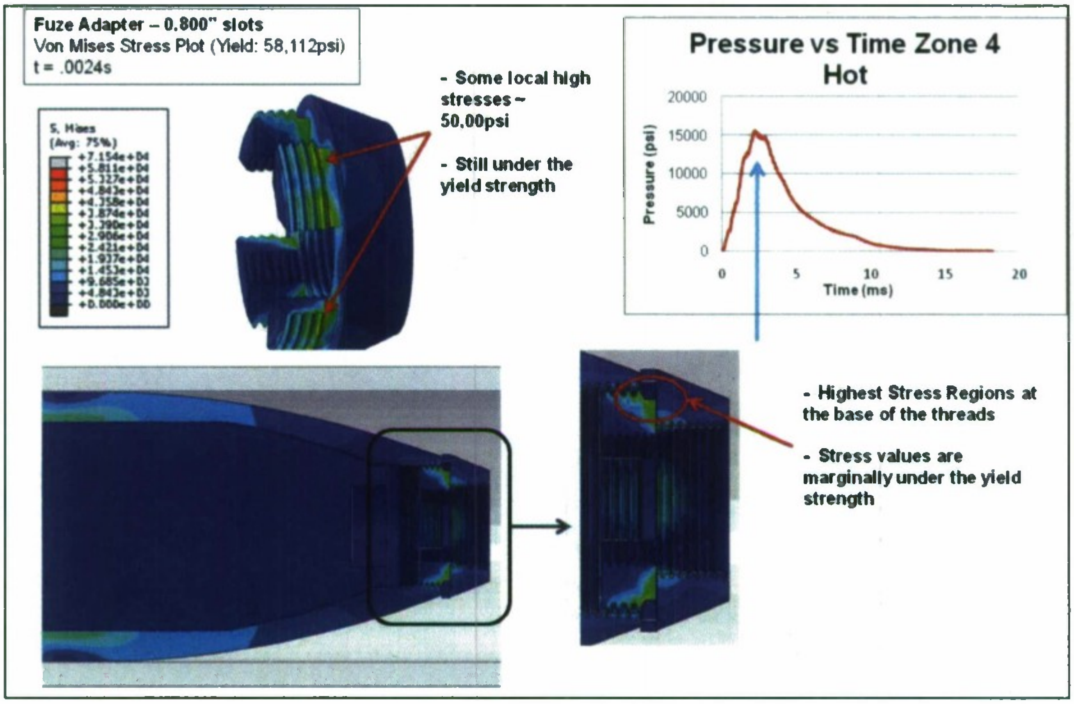

Figure 13
Von Mises stress contour plots of the fuze adapter with 0.800-in. slots at t = 0.0024s

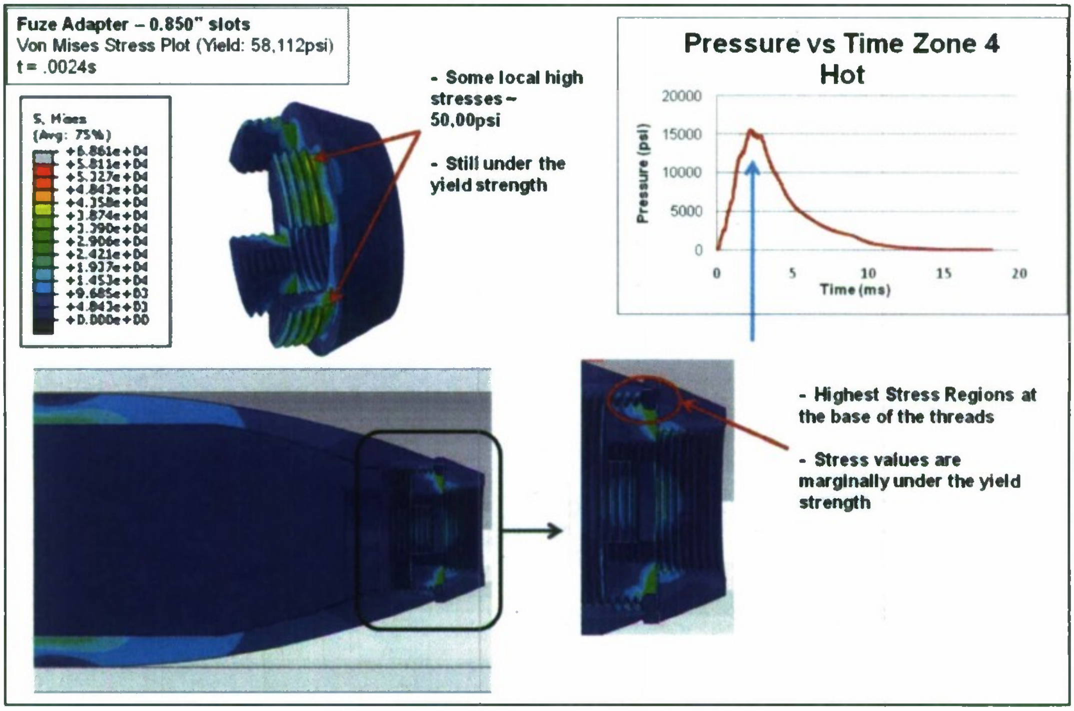

Figure 14
Von Mises stress contour plots of the fuze adapter with 0.850-in. slots at t = 0.0024s

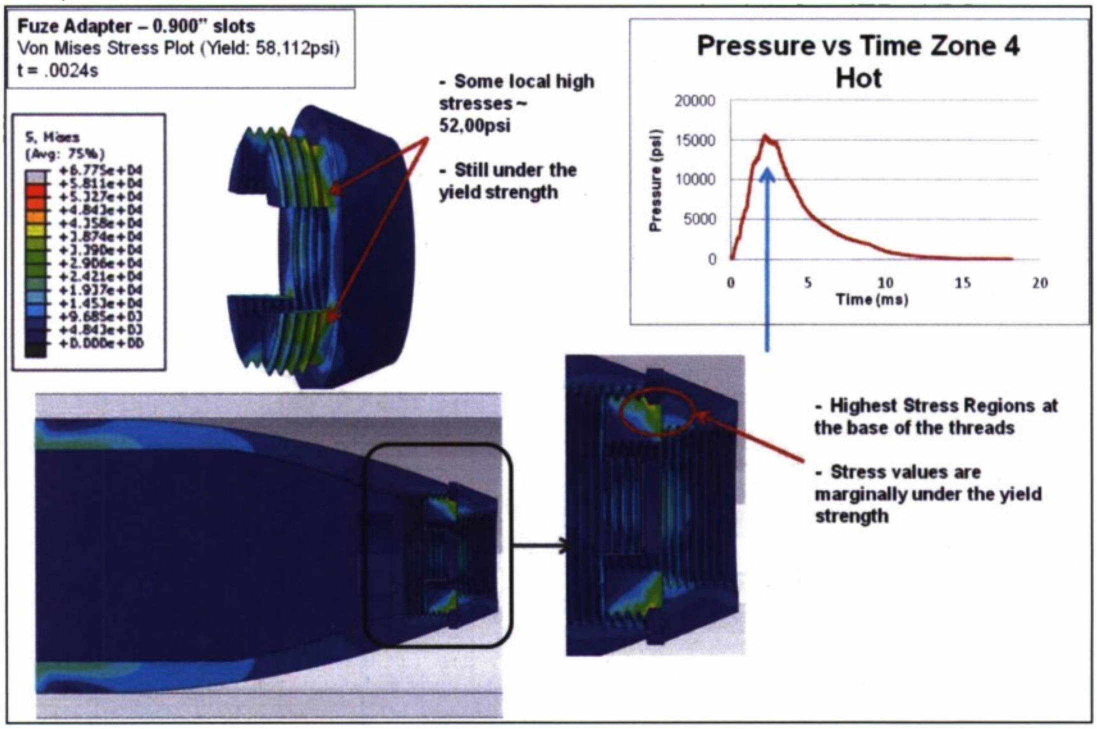

Figure 15
Von Mises stress contour plots of the fuze adapter with 0.900-in. slots at t = 0.0024s

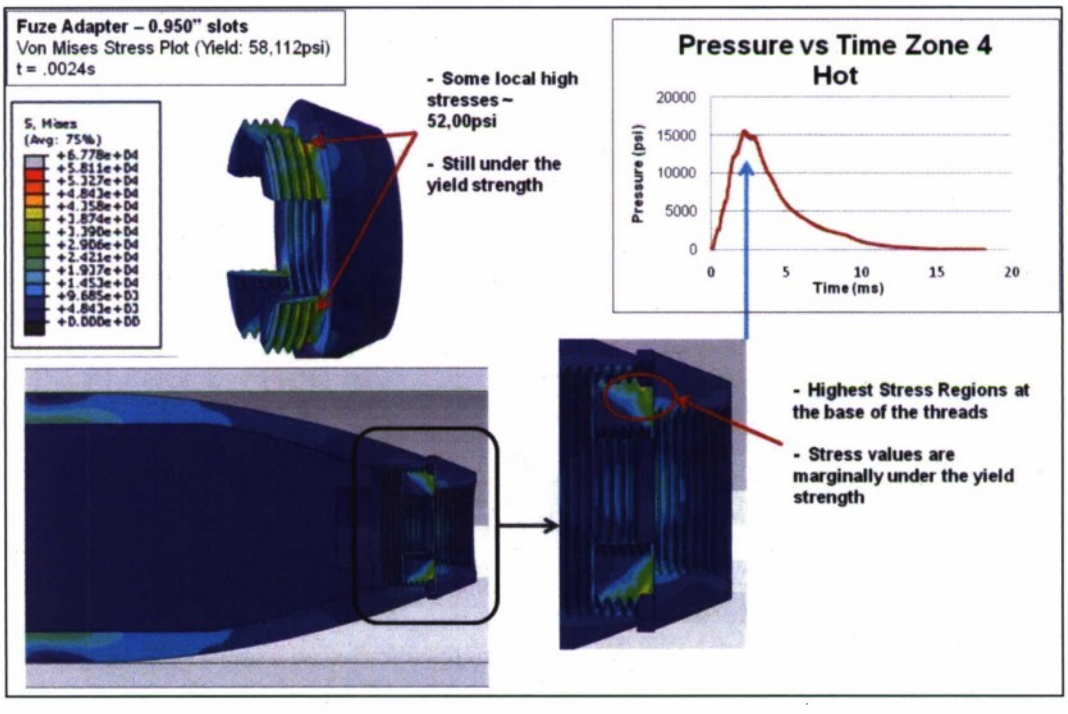

Figure 16
Von Mises stress contour plots of the fuze adapter with 0.950-in. slots at t = 0.0024s

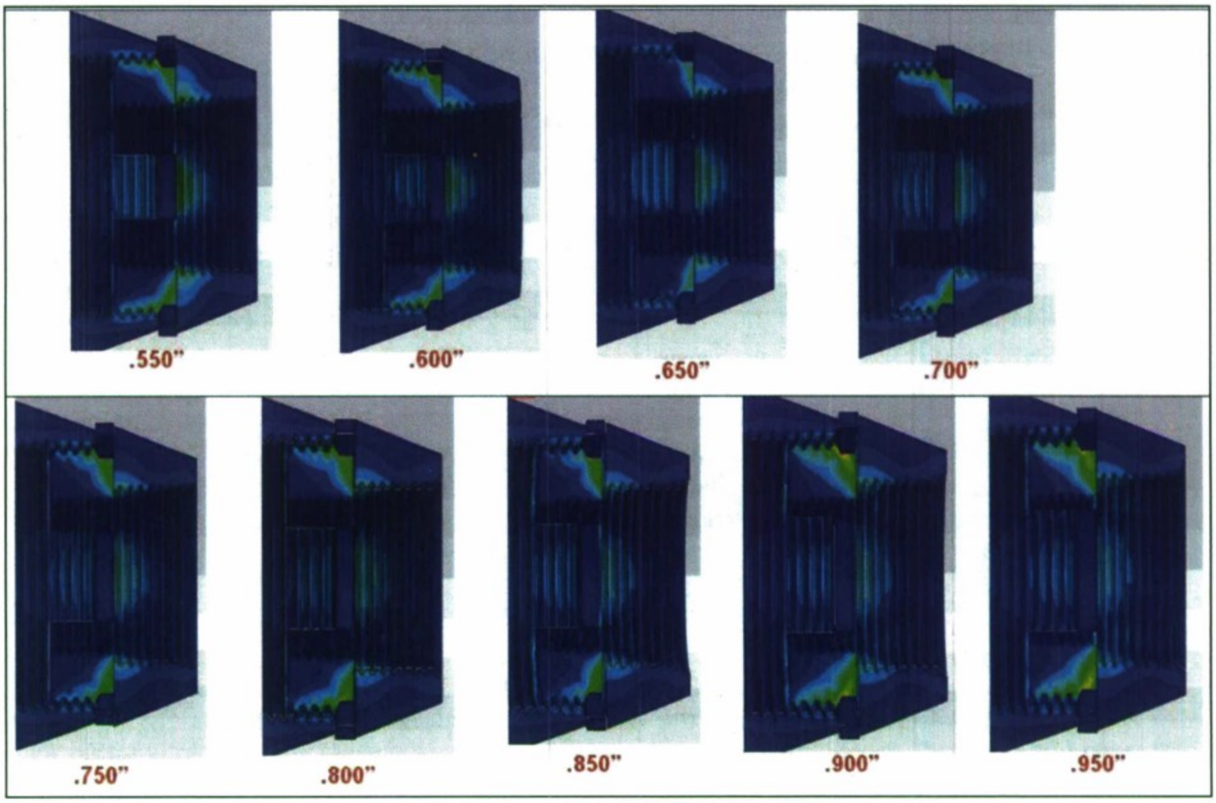

Figure 17
Von Mises stress contour plots of the fuze adapter with varying slot widths

DISCUSSION

The purpose of the analysis was to determine the length of gaps that could be supported in the forward joint of a 120-mm mortar. The mortar must survive gun launch pressures up to 16,000 psi, which is typical for Zone 4-hot charge. The purpose of the slots was to allow pressure relief in the unlikely event of a SCO. Since this may be a safety-critical issue, assumptions should be carefully reviewed and validated. As always, actual tests will precede material release to the Warfighter.

Several assumptions regarding geometry were made. The fuze was modeled as a point mass rather than as its external shape or a detailed fuze. As long as the loads are axisymmetric, this probably has little effect on the forward joint. Dimensions were taken as nominal values from the Pro/E files. Since the resulting stresses were below the yield strength, the slight reduction due to tolerances would probably not affect the analytic outcome. The threads were modeled as circumferential rather than helical. Again, this geometric assumption has little effect on this analysis provided unwinding of the joint is unlikely. (A joint torsion study was not completed.)

Material strengths and elongations were determined from literature values rather than measured statistical values. There is high confidence in the yield strength for the 7075-T6 aluminum, since it was taken from the "Metallic Materials Properties Development and Standardization" handbook, which is a known statistical low value (ref. 7). The material properties for the HF-1 steel should be confirmed by statistics. The strength of the gasket material should also be confirmed as a statistical low value.

Loads were derived from the worst of Zone 4-hot pressure time curves rather than from statistics. In previous studies on mortars (ref. 4), 3-sigma statistical pressure maxima were used. This may be significant, if the 3-sigma load is much higher than the assumption. Internal cook-off pressures were not included in the analysis. All loads were assumed to be axisymmetric. Based on the Penn State study and previous fin failures, this may or may not be true in the forward joint of the mortar (refs. 1 and 2).

Friction in the threads is unknown and probably variable from mortar to mortar. A limited friction study was completed. Results with a 0.3 coefficient of friction did not lead to significant changes in the stress distribution from the frictionless assumptions in the figures 7 through 17.

CONCLUSIONS

The finite element analysis (FEA) simulated this dynamic and transient event. The results of the analysis verify the survivability of the reduced thread fuze adapter concept using the given assumptions. The fuze adapter with radial slots will survive gun launch for slot widths up to 0.950 in. The gasket will also survive the gun launch environment, but has marginal survivability. The FEA results supply the customer with the information needed to confidently proceed with this reduced thread fuze adapter.

REFERENCES

1. Cordes, J.A.; Rand, H.; Carlucci, D.; Reinhardt, L.; and Kerwien, S., "Predicting the Cause of Failure in 120-mm Mortar Fins," Technical Report ARSFD-TR-03002, U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, July 2003.

2. Kuo, K. K.; Boyer, E.; and Martin, H.T., "Detailed Ballistic Performance Characterization of 120-mm Mortar System with Different Flash Tube Configuration," To be published.

3. Cordes, J.A., L. E. Reinhardt; G. E. Matty; and P.E. Van Dyke, "Modeling and Simulation In Support of a Root Cause Investigation of an 81 mm M821A1 Mortar," Technical Report ARMET-TR-11003, U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, To be published.

4. Cordes, J.A.; Thomas, J.; Wong, R.S.; and Carlucci, D., "Reliability Estimates For Flawed Mortar Projectile Bodies," Reliability, Engineering & System Safety, Volume 94, Issue 12, pages 1887-1893, 2009.

5. Jablonski, J.; Cordes, J.A.; Hespos, M.; Geissler, D.; and Carlini, M., "Critical Flaw Estimate and Flaw Analysis of 81-mm M821A1 Mortar Projectile," Technical Report ARMET-TR-10001, U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, June 2010.

6. "Abaqus User Manual V6.10.1," Dassault Systems 2004-2010.

7. Rice, R.C.; Jackson, J.L.; Bakuckas, J.; and Thompson, S., "Metallic Materials Properties Development and Standardization (MMPDS)," DOT/FAA/AR-MMPDS-01, Office of Aviation Research, Washington, D.C. 20591, 2003.

8. http://www.matweb.com/

DISTRIBUTION LIST

U.S. Army ARDEC
ATTN: RDAR-EIK
RDAR-GC
RDAR-MEF, W. Smith
RDAR-ME, J. Hedderich
RDAR-MEF-F, R. Terhune
RDAR-MEF-E, D. Troast
A. Totten
J. Cordes
RDAR-MEE-W, S. DeFisher
RDAR-MEM-M, R. Wong
Picatinny Arsenal, NJ 07806-5000

Defense Technical Information Center (DTIC)
ATTN: Accessions Division
8725 John J. Kingman Road, Ste 0944
Fort Belvoir, VA 22060-6218

Commander
Soldier and Biological/Chemical Command
ATTN: AMSSB-CII, Library
Aberdeen Proving Ground, MD 21010-5423

Director
U.S. Army Research Laboratory
ATTN: AMSRL-CI-LP, Technical Library
Bldg. 4600
Aberdeen Proving Ground, MD 21005-5066

Chief
Benet Weapons Laboratory, WSEC
U.S. Army Research, Development and Engineering Command
Armament Research, Development and Engineering Center
ATTN: RDAR-WSB
Watervliet, NY 12189-5000

Director
U.S. Army TRADOC Analysis Center-WSMR
ATTN: ATRC-WSS-R
White Sands Missile Range, NM 88002

Chemical Propulsion Information Agency,
ATTN: Accessions
10630 Little Patuxent Parkway, Suite 202
Columbia, MD 21044-3204

GIDEP Operations Center
P.O. Box 8000
Corona, CA 91718-8000