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Vented Fixture Modeling

by Paul Conroy

ARL-TR-2952

April 2003

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ARL-TR-2952 **April 2003**

Vented Fixture Modeling

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Abstract

Vented fixtures have been used extensively for erosion/erosivity investigation for many years. The fixtures can assist in quickly assessing materials/propellants and interactions as well as understanding mechanisms of erosion. In this report, two fixtures are modeled—a 37-mm fixture at the U.S. Army Research Laboratory and a 200-mm^3 bomb with a 1-mm vent hole, located in Canada. Both fixtures erode a nozzle-type insert. The 37-mm fixture is designed to maintain a steady erosion quantity over repeated firings, with relatively small throat cross-sectional area change, which enables some insight into possible mechanisms. Each interior ballistic model required modifications to the interior ballistic code to enable a variable throat exit for the orifice. The Canadian fixture has a 1-mm vent hole, which has a tendency to enlarge considerably during firing. The dominant erosion mechanism for the Canadian fixture is shown to be melt wipe, while for the 37-mm fixture, it is primarily thermochemical. A redesign of the Canadian fixture to permit a larger exit orifice with a rupture diaphragm would enable thermochemical differences in the propellants to reveal themselves better.

Acknowledgments

Thanks goes to Drs. France Beaupré and Louis-Simon Lussier of the Defence Research Establishment of Valcartier, Canada, for graciously permitting my use of their experimental findings in this report. Thanks also to Mr. Charles Leveritt for the U.S. Army Research Laboratory experimental data.

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1. Introduction

The vented fixture has been applied to gun tube erosion since WWII (Ritchie 1942). Vented fixtures typically consist of an initially closed vessel, which has a vent port and diaphragm. Upon ignition of the propellant in the fixture, the pressure rises until the rupture pressure is reached and the diaphragm is ejected. The flow of combustion products past a test sample is then used to gage the erosivity of a particular propellant or erosion resistance of a particular material or coating through measurements such as diametral change, sample mass loss, etc.

This current study focuses upon the modeling of various vented fixtures, namely the U.S. Army Research Laboratory (ARL) 37-mm fixture, and a Canadian fixture using two radically different propellants—M30 (triple base) and M43, and nitramines in each fixture. Finite rate chemistry has been incorporated into the ARL Gun Tube Erosion code (ATEC) and reported (Conroy and Nusca 2001; Conroy et al. 2000). Previously, there was a melt-wipe model (Weinacht and Conroy 1996), followed by a generalized equilibrium model (Conroy et al. 1997, 1998, 1999). The melt-wipe description enabled very severely eroding systems to be modeled (Conroy et al. 1997, 1999); however, it did not account for the effects seen in spite of the lower adiabatic flame temperature of the M43 to that of the M30. The erosivity of the M43 is typically higher (Ward et al. 1981). This behavior conflicts with previously held beliefs and correlations, which were based only upon flame temperature.

2. Experimental/Numerical Results

Beginning with the modeling efforts focused on the 37-mm ARL erosion fixture, a general diagram is presented in Figure 1, and a similar photograph is presented in Figure 2. Note that there is a rupture diaphragm downstream of the experimental test section shown in Figure 1. The material used in the experiment is from an M68 tank cannon.

As was stated, both M30 and M43 propellants were fired in this fixture, and the resulting pressure-time curves, along with matching Express Kinetics Traveling Charge Code (XKTC) calculations (Gough 1990), are presented for both M30 and M43 propellants in Figures 3 and 4, respectively.

The chamber volume for the 37-mm ARL fixture is 356 cm^3, with 73.2 g of M30 resulting in a loading density of 0.205 g/cm^3 for the M30 firing and a loading density of 0.189 g/cm^3 for the M43 firing. These loading densities were determined by Leveritt et al. (2000) to produce enough pressure to rupture the diaphragm at "burn-out."

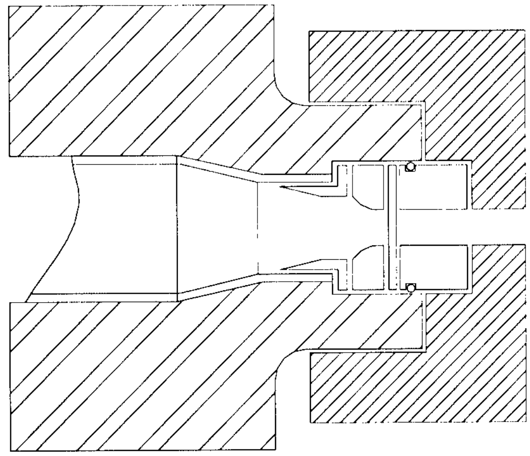

Figure 1. ARL 37-mm erosion test fixture showing test nozzle and rupture diaphragm.

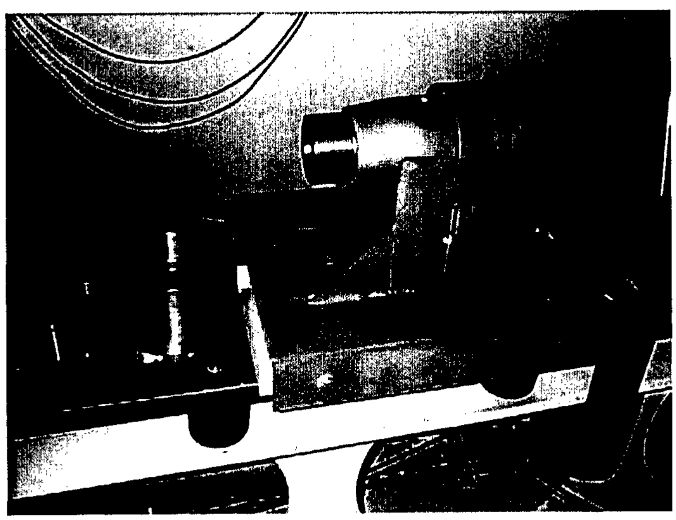

Figure 2. Photograph of ARL 37-mm vented fixture.

The model to predict erosion has been previously described (Conroy and Nusca 2001; Conroy et al. 2000). The model includes independent heat and mass transport to the surface, avoiding assumptions concerning molecular weights of species being the same. It also has subsurface heat and mass transport, along with substrate stress calculations, including surface coating effects and their interfacial stresses. This enables cracks to be formed. Thermally variable material properties are included. At the interface between the gas and solid phase, a true finite rate kinetics calculation is performed using reactions and rates. The user may supply as many reactions and rates as desired. Beneath the surface and equilibrium reaction, calculation is performed to react the diffused gas phase species with the condensed materials. This results in new species with differing properties than that of the original gun material. Figure 5 provides a cartoon of the model.

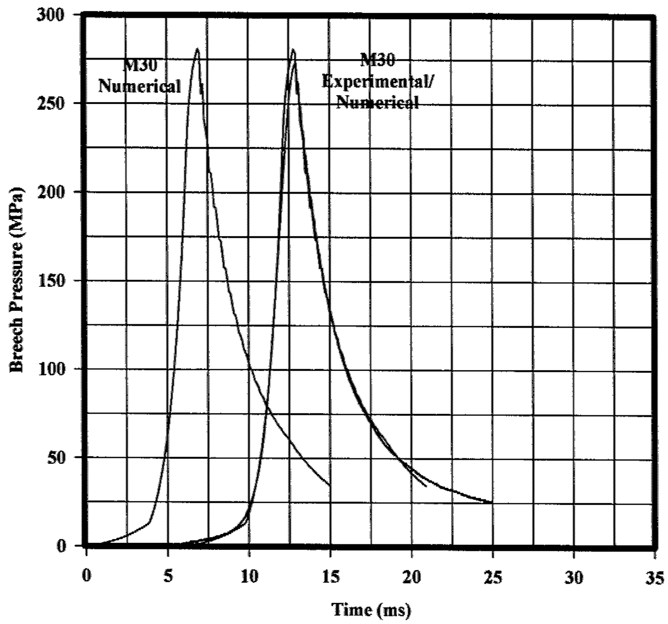

Figure 3. Numerical and experimental pressure for ARL 37-mm vented combustor firing 73.2 g of M30 propellant.

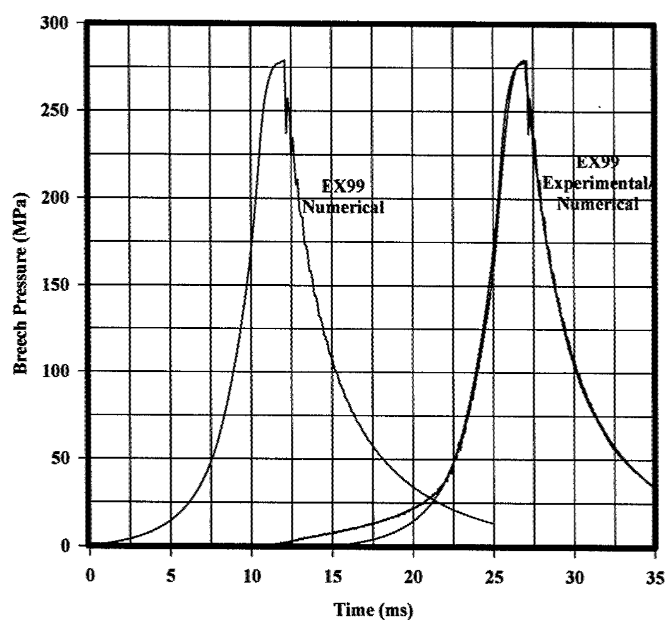

Figure 4. Numerical and experimental pressure for ARL 37-mm vented combustor firing 67.3 g of EX99 propellant.

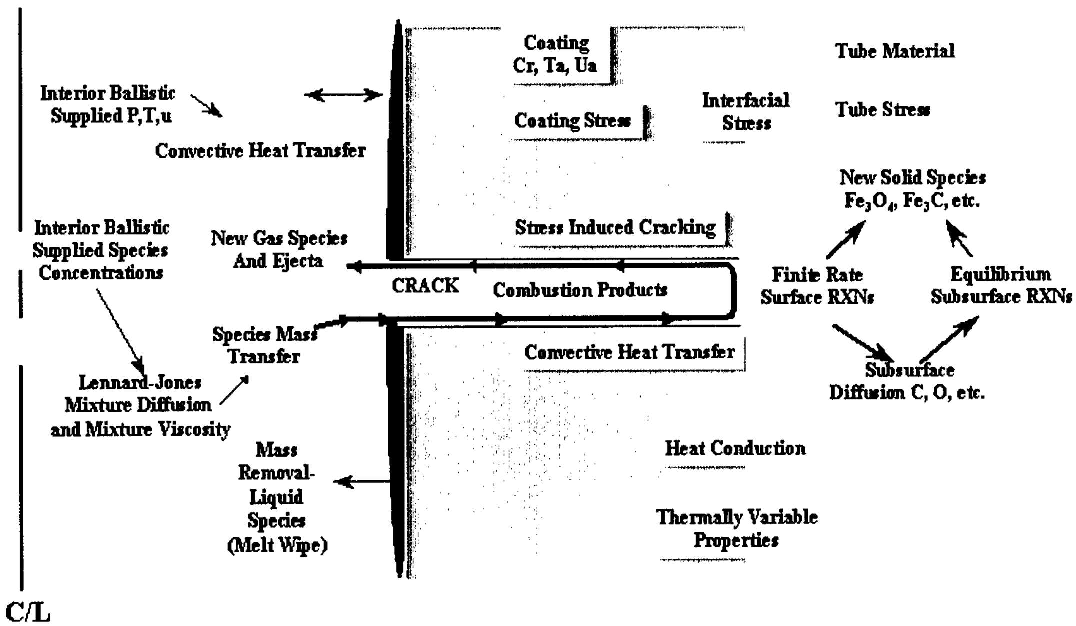

Figure 5. Cartoon describing the erosion model.

Using the interior ballistic output as input to the model for both the EX99 and M30 firings resulted in the erosion prediction shown in Figure 6. It is interesting that even though both the loading density and adiabatic flame temperature were higher for the M30, the erosion was greater for the EX99 propellant.

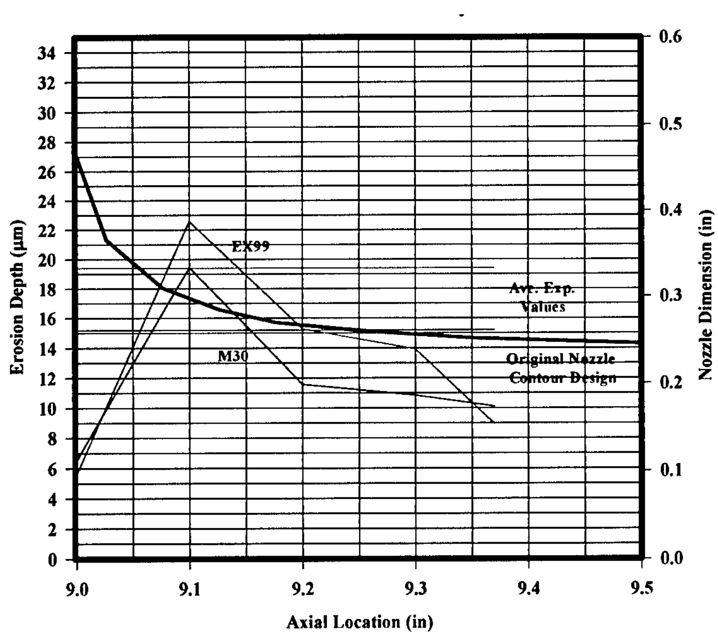

Figure 6. Numerical prediction of ARL 37-mm vented fixture nozzle recession firing M30 and EX99 propellant.

Figure 6 also includes a contour of the original nozzle shape. The maximum erosion can be seen to occur in the entrance portion of the nozzle. The erosion is minimal where the axial gas velocities are low, such as at the entrance edge of the nozzle. The integrated material mass loss was very close to that of the experiment.

The second vented fixture examined numerically was the Canadian fixture, which is a different configuration than the ARL fixture (Beaupré et al. 2001). Figure 7 shows a schematic of the fixture, and Figure 8 shows a photograph including the erosion grain. The specifications of the chamber are 200 cm^3, no rupture disk, and an erosion grain, which chokes the flow. The erosion grain is 20 mm long $\times$ 19 mm in diameter, with a 1-mm hole drilled through, made of an agreed upon material from an M68 tank cannon. Firings were performed with both M30 and EX99 propellants. A representative firing for each was chosen for modeling purposes. (Note: experimental data and photos were included with permission from Dr. Louis-Simon Lussier of the Defence Research Establishment of Valcartier, Canada).

The EX99 firing, of which the pressure time plot is presented in Figure 9, was performed using 30.2 g of EX99, with a loading density of 0.15g/cm^3, and had a maximum pressure of 199 MPa. The numerical representation of the fixture, which matches the experimental pressure well even through the blow-down period after peak pressure, is also presented in Figure 9.

The M30 firing result chosen for modeling purposes is presented in Figure 10, where 40.2 g of M30 were fired, creating a loading density of 0.20 g/cm^3, which resulted in a maximum pressure of 268 MPa. Again, the numerical results are presented and match reasonably well.

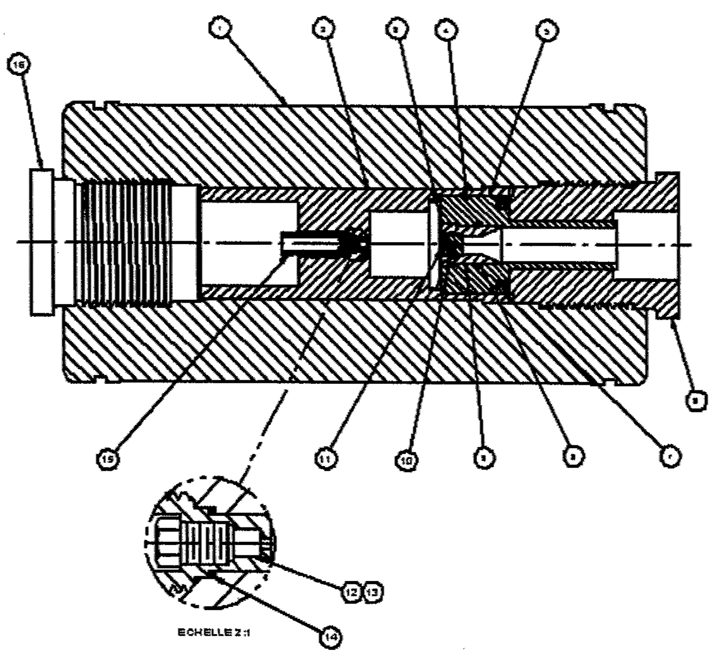

Figure 7. Canadian erosion grain vented vessel.

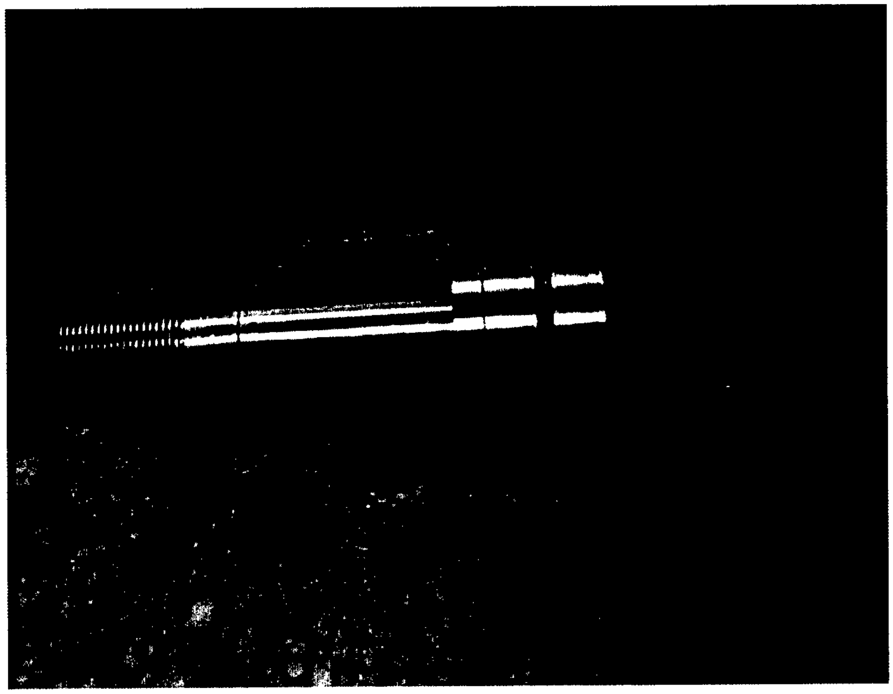

Figure 8. Schematic of the vented vessel plug containing the erosion grain.

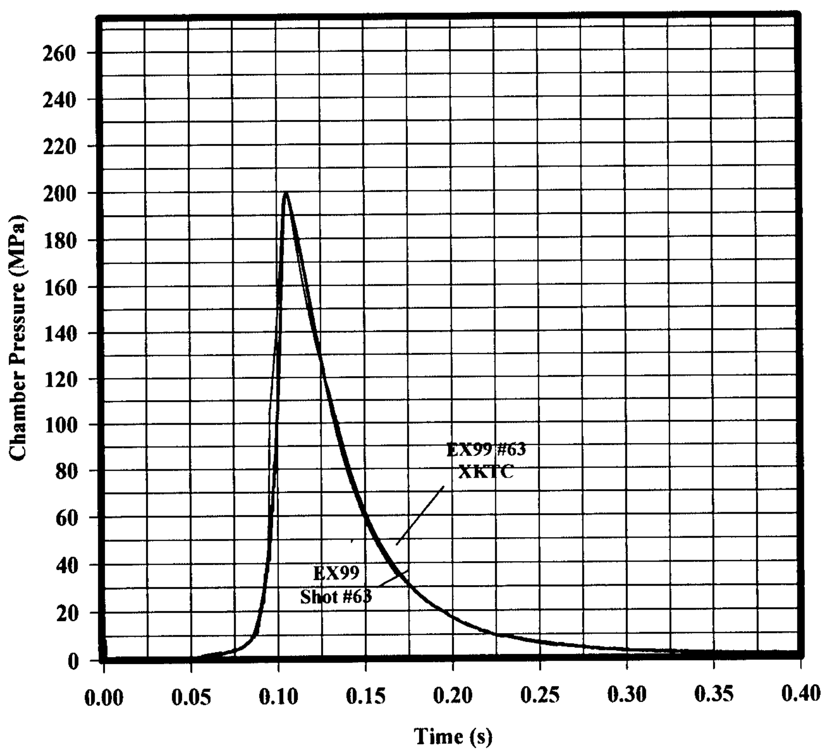

Figure 9. Experimental and numerical pressure for Canadian erosivity fixture firing no. 63 with 30.2 g of EX99 propellant.

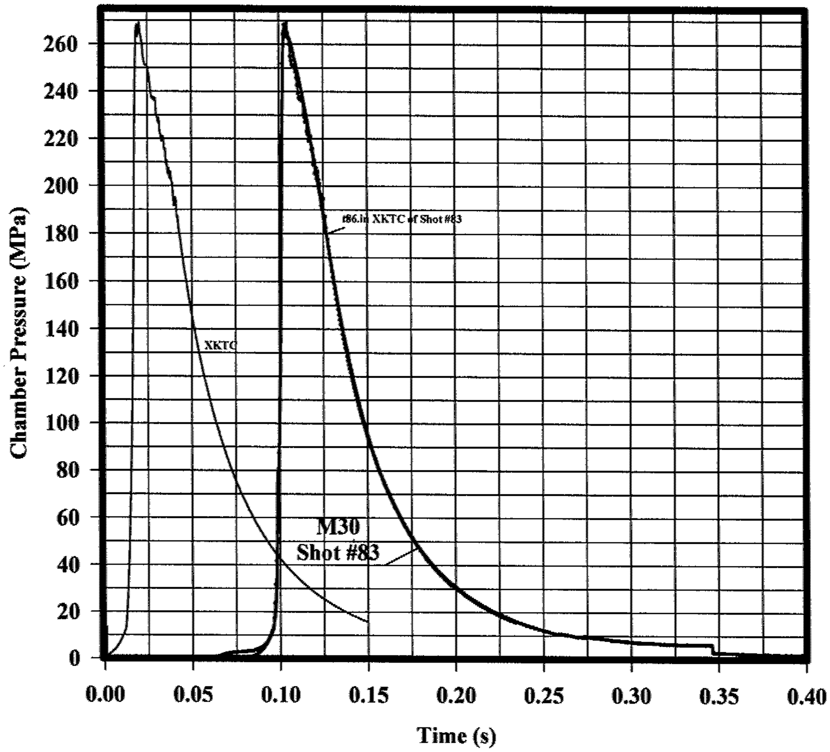

Figure 10. Experimental and numerical pressure for Canadian erosivity fixture firing no. 83 with 40.2 g of M30 propellant.

The Canadian fixture did not include a rupture diaphragm and therefore had continuous mass flux through the orifice for the entire ballistic cycle. Also, the vent opening was not contoured to provide an optimal entrance region for the flow. Figure 11 shows the resulting computed and average experimental erosion values plotted along the vent plug. Interestingly, the computed erosion shows that a curved entrance will result, as seen experimentally in Figure 12 (Beaupré and Lussier 2002). Again, in this fixture, the EX99 shows higher erosivity than that of the M30, even though the M30 had a much higher loading density and resulting peak pressure.

3. Discussion

The model is versitile enough to handle vented erosion fixtures. The numerical results are in good agreement with the experimental results both quantitatively and analytically. The EX99 propellant erodes more than the M30 propellant, even at lower peak pressures and loading densities. Similar results were seen by Ward et al. (1981).

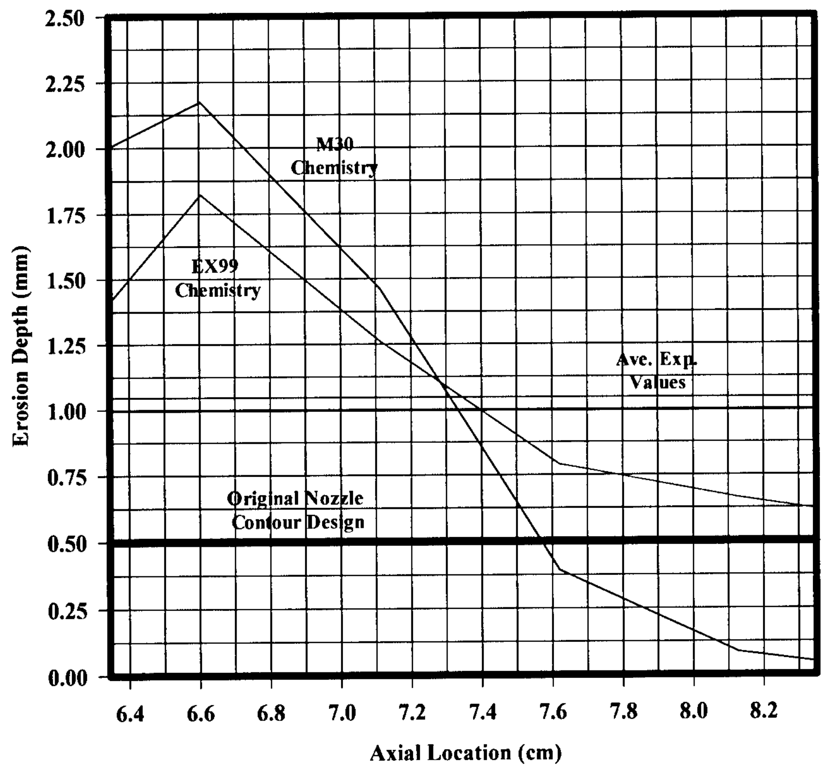

Figure 11. Numerical prediction of Canadian vented fixture nozzle recession firing M30 and EX99 propellants, with corresponding ballistic pressures provided in Figures 9 and 10.

Figure 12. Before and after photos of Canadian nozzles firing M30 propellant (after Beaupré and Lussier [2002]).

The mechanism exercised in the ARL fixture was primarily chemistry-driven modified material melt wipe in which the material had a considerably lowered melt temperature from that of the virgin gun steel. The mechanism in the Canadian fixture involved both chemistry as well as melting of the bulk material at the peak of the ballistic cycle. The reason for the higher mass loss of EX99 over M30 is due to the composition of EX99, resulting in more carbon monoxide (CO) production than that of M30. This is evident in both the Canadian and ARL fixtures. The CO/carbon dioxide (CO_2) ratio for EX99 is 7.78, while that for the M30 is 3.1 (Leveritt et al. 2000). This additional CO makes more CO available on the surface for dissociation. The dissociated CO then provides free carbon for absorption into the steel lattice, which then forms iron carbides with a much reduced melt/softening temperature, 1423 K, than that of the virgin material with a melt/softening temperature of about 1723 K.

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
April 2003	Final	October 2000–October 2001

4. TITLE AND SUBTITLE
Vented Fixture Modeling

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Paul Conroy

5d. PROJECT NUMBER
622618.H80

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WM-BD
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-2952

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

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15. SUBJECT TERMS
erosion, heat transfer, surface kinetics, wear, vented fixture, vented bombs, M30, EX99

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL	24	Paul Conroy
					19b. TELEPHONE NUMBER *(Include area code)* 410-278-6114

Standard Form 298 (Rev. 8/98)
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