Technical Report ARMET-TR-13009

AN EMPIRICAL SHAPED CHARGE JET BREAKUP MODEL

Ernest L. Baker
James Pham
Tan Vuong

July 2014

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
Munitions Engineering Technology Center
Picatinny Arsenal, New Jersey

Approved for public release; distribution is unlimited.
The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

The citation in this report of the names of commercial firms or commercially available products or services does not constitute official endorsement by or approval of the U.S. Government.

Destroy this report when no longer needed by any method that will prevent disclosure of its contents or reconstruction of the document. Do not return to the originator.
**REPORT DOCUMENTATION PAGE**

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden to department of defense, Washington Headquarters Services Directorate for information operations and reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

**PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

<table>
<thead>
<tr>
<th>1. REPORT DATE (DD-MM-YYYY)</th>
<th>July 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. REPORT TYPE</td>
<td>Final</td>
</tr>
<tr>
<td>3. DATES COVERED (From - To)</td>
<td></td>
</tr>
</tbody>
</table>

**4. TITLE AND SUBTITLE**

AN EMPIRICAL SHAPED CHARGE JET BREAKUP MODEL

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**6. AUTHORS**

Ernest L. Baker, James Pham, and Tan Vuong

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

U.S. Army ARDEC, METC
Energetics and Warheads & Manufacturing Technology Directorate (RDAR-MEE-W)
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-13009

**12. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

Much of the increase in penetration capability of copper lined shaped charges has been due to changes that increased copper jet breakup time. This has been accomplished largely independent of the growing understanding of breakup phenomenology. This report discusses an empirical shaped charge jet breakup model and provides significant experimental confirmation over a broad range of velocity gradients. Analysis using this model has proved to be useful in order to explain observed performance and to identify undesirable characteristics.

**15. SUBJECT TERMS**

Shaped charge jet break up model  Copper lined shaped charge  Increase in penetration capability
Increased copper jet break up time  Jet break up formulation

**16. SECURITY CLASSIFICATION OF:**

UNCLASSIFIED

**17. LIMITATION OF ABSTRACT**

SAR

**18. NUMBER OF PAGES**

13

**19a. NAME OF RESPONSIBLE PERSON**

Kathleen A. Walsh

**19b. TELEPHONE NUMBER (include area code)**

(973) 724-7014

---

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

Mr. James Pearson (retired), U.S. Army Armament Research, Development & Engineering Center, Picatinny Arsenal, NJ, for his insightful theoretical development and diligent data analysis that provided the genesis of the presented work.
INTRODUCTION

The parameters that affect jet length and breakup times are fairly well known, but there is some controversy over the exact nature of the dependencies. Walsh, J.M. (1984), theorized that the dependence of jet length would take a particular form based on his determination of a dimensionless parameter for the problem and numerical experiments in which initial perturbation strengths were varied (ref. 1). Walsh did not present comparisons with experimental results. Chou, P.C. (1986), has presented a variety of different jet breakup models with some data comparisons (ref. 2).

Mostert, F.J. (1995), has suggested that breakup time is proportional to \( \left( \frac{\Delta m}{\Delta v} \right)^{1/3} \) where \( m \) is the accumulated jet mass and \( v \) is the jet velocity associated with the final accumulated jet mass versus jet velocity characterization starting from the jet tip (ref. 3). The values of \( \Delta m \) and \( \Delta v \) are respectively the jet mass and the velocity difference of the portion of jet in question. For a typical shaped charge, \( \frac{\Delta m}{\Delta v} \) is essentially invariant with respect to time after jet formation is complete. The parameter \( \frac{\Delta m}{\Delta v} \) or \( \left( \frac{dm}{dv} \right)^{1/3} \) is closely related to Walsh’s dimensionless parameter.

BREAKUP FORMULATION

The analysis and data provided are for ductile jets, i.e., the radius at the neck goes to zero at failure. Walsh theorized that the final length \( L_b \) of an element of stretching (elastic perfectly plastic) jet with initial length \( L_0 \) should be given by (eq. 1)

\[
L_b = L_0 \left( \frac{\sigma}{\rho} \right)^{2/3} \left( \frac{R}{\rho_0^{0.05} \phi_0^{0.22}} \right), \quad \phi = \frac{\sigma}{\rho} R^2
\]

(1)

Where all parameters are defined at the moment of jet formation, \( \phi \) is a dimensionless parameter, \( u_x \) is velocity gradient, \( R \) is jet radius, \( \sigma \) and \( \rho \) are respectively jet strength and density and \( \phi \) is a perturbation strength term. Walsh was led to this theory by dimensionless analysis and numerical simulations in which he investigated the effects of various types of perturbations and perturbation strengths. Walsh made no comparisons with experimental data. Let \( dL_0 \) be a differential increment of jet length, then \( u_x = \frac{dv}{dL_0} \) where \( dv \) is the velocity difference across the increment.

Then (eq. 2)

\[
\rho^{2/3} dL_0 u_x^{2/3} R^{2/3} = \left( \rho R^2 dL_0 \right)^{1/3} \left( \frac{dm}{dv} \right)^{1/3} dv, \quad \text{where} \quad dm = \frac{d\rho}{\sigma} = \rho R^2 dL_0
\]

(2)

Finally (eq. 3)

\[
dL_b = \frac{1}{\sigma^{2/3}} \left( \frac{dm}{dv} \right)^{1/3} dv \left[ \frac{C}{\rho_0^{0.05} \phi_0^{0.22}} \right]
\]

(3)

In the virtual origin approximation (Chou) \( dL_b = \beta dv \).
Hence (eq. 4)

$$t_b = \frac{1}{\sigma^{1/3}} \left( \frac{dm^*}{dv} \right)^{1/3} \left[ \frac{C}{\Phi^{.05} \Phi^{.22}} \right]$$

This equation can be rearranged into a form in which the quantities that can be measured or estimated, $t_b$ and $\frac{dm^*}{dv}$, are separate from those that cannot be measured or estimated.

**EMPIRICALLY-BASED JET BREAKUP MODEL**

The resultant jet breakup formulation is (eq. 5)

$$Q = \left( \frac{t_b}{\left( \frac{dm^*}{dv} \right)^{1/3}} \right) = \frac{1}{\sigma^{1/3}} \left[ \frac{C}{\Phi^{.05} \Phi^{.22}} \right]$$

For convenience, this ratio will be referred to as $Q$, the ductility factor, and is treated as an empirically determined material parameter. As the quantity $\frac{dm^*}{dv}$ is essentially invariant after jet breakup, it can be determined from x-rays of particulated jets or estimated from numerical simulations of shaped charge collapse and jet formation. Table 1 presents reduced data from jet x-rays and numerical simulations used for the data analysis. Figure 2 presents resultant plots comparing the reduced data to various levels of $Q$, the ductility factor.

<table>
<thead>
<tr>
<th>Device</th>
<th>$tb$ from</th>
<th>$tb/D$ (µs/mm)</th>
<th>$\frac{dm^*}{dv}$ from</th>
<th>$\frac{1}{D} \left( \frac{dm^*}{dv} \right)^{1/3}$</th>
<th>$Q = \frac{t_b}{\left( \frac{dm^*}{dv} \right)^{1/3}}$</th>
<th>$\frac{Q_{slow}}{Q_{fast}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>81.3mm Cu cone</td>
<td>$dL_v$</td>
<td>2.07 slow</td>
<td>1.75 fast</td>
<td>0.347</td>
<td>59.7</td>
<td>0.995 1.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.39 tail</td>
<td>0.267 tip</td>
<td>0.195</td>
<td>71.3</td>
<td>1.19 2.59</td>
</tr>
<tr>
<td>38.1mm Cu hemi</td>
<td>$L_v$</td>
<td>3.09</td>
<td>2.33 slow</td>
<td>0.690</td>
<td>31.6</td>
<td>0.97 1.14</td>
</tr>
<tr>
<td>38.1mm Cu 90° cone</td>
<td>$L_v$</td>
<td>1.38</td>
<td>1.48 mid</td>
<td>0.575</td>
<td>53.7</td>
<td>0.90 1.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.44</td>
<td>1.80 mid</td>
<td>0.575</td>
<td>53.7</td>
<td>0.90 1.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.39 tail</td>
<td>1.13 fast</td>
<td>0.35</td>
<td>66.6</td>
<td>0.97 1.32</td>
</tr>
<tr>
<td>76.2mm Cu hemi</td>
<td>$dL_v$</td>
<td>2.18 slow</td>
<td>1.78 fast</td>
<td>0.547</td>
<td>32.5</td>
<td>0.54 0.97</td>
</tr>
<tr>
<td>140mm Cu trun. cone</td>
<td>$L_v$</td>
<td>2.73</td>
<td>2.73 slow</td>
<td>0.547</td>
<td>32.5</td>
<td>0.54 0.97</td>
</tr>
<tr>
<td>150mm Cu trumpet</td>
<td>$L_v$</td>
<td>2.33 slow</td>
<td>1.80 mid</td>
<td>0.473</td>
<td>57.7</td>
<td>0.96 1.14</td>
</tr>
<tr>
<td>150mm Cu Free form</td>
<td>$tb$</td>
<td>1.39 tail</td>
<td>1.13 fast</td>
<td>0.35</td>
<td>66.6</td>
<td>0.97 1.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.267 tip</td>
<td>0.22</td>
<td>0.35</td>
<td>66.6</td>
<td>0.97 1.32</td>
</tr>
</tbody>
</table>

Approved for public release; distribution is unlimited.
ALE modeling of shaped charges for jet characterization. Dislocation percolating on (111) plane with SFT's

Ductility factor data for various copper shaped charges
REFERENCES


DISTRIBUTION LIST

U.S. Army ARDEC
ATTN:  RDAR-EIK
       RDAR-GC
       RDAR-MEE-W. E. Baker
       J. Pham
       T. Vuong
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
"An Empirically Based Shaped Charge Jet Break-Up Model"

PART 1. **Must be signed before the report can be edited.**

a. The draft copy of this report has been reviewed for technical accuracy and is approved for editing.

b. Use Distribution Statement A, B, C, D, E, F, or X for the reason checked on the continuation of this form.

1. If Statement A is selected, the report will be released to the National Technical Information Service (NTIS) for sale to the general public. Only unclassified reports whose distribution is not limited or controlled in any way are released to NTIS.

2. If Statement B, C, D, E, F, or X is selected, the report will be released to the Defense Technical Information Center (DTIC) which will limit distribution according to the conditions indicated in the statement.

c. The distribution list for this report has been reviewed for accuracy and completeness.

Steven M. Nicolich
Division Chief
(Date)

PART 2. To be signed either when draft report is submitted or after review of reproduction copy.

This report is approved for publication.

Steven M. Nicolich
Division Chief
(Date)

Stephen Leong

SMCAR Form 49, 20 Dec 06 supersedes SMCAR Form 49, 1 Nov 94.