AMRA TR 66-33

ATTENUATION OF FRAGMENT VELOCITIES DUE TO THE DEFORMATION RESISTANCE OF THE CASING

TECHNICAL REPORT

by

GORDON A. BRUGGEMAN

OCTOBER 1966

Distribution of this document is unlimited

U. S. ARMY MATERIALS RESEARCH AGENCY
WATERTOWN, MASSACHUSETTS 02172

DISPOSITION INSTRUCTIONS

ATTENUATION OF FRAGMENT VELOCITIES DUE TO THE
DEFORMATION RESISTANCE OF THE CASING

Technical Report AMRA TR 66-33

by

Gordon A. Bruggeman

October 1966

U. S. ARMY MATERIALS RESEARCH AGENCY
WATERTOWN, MASSACHUSETTS 02172

U. S. ARMY MATERIALS RESEARCH AGENCY

ATTENUATION OF FRAGMENT VELOCITIES DUE TO THE DEFORMATION RESISTANCE
OF THE CASING

ABSTRACT

Estimates are made of the energy required to expand an exploding shell casing relative to the kinetic energies of the fragments. It is shown that the energy of deformation detracts very little from the ultimate fragment velocities.

BLANK PAGE

ATTENUATION OF FRAGMENT VELOCITIES DUE TO THE DEFORMATION RESISTANCE
OF THE CASING

In predicting the velocity of fragments produced by an exploding shell, neither Gurney[1] nor Thomas[2] take into consideration the energy required to expand the metal casing against the resulting tensile stresses which produce the plastic flow. Observations that the fragment velocities obtained with relatively brittle materials, such as cast iron, are essentially the same as those obtained with ductile casing materials would indicate that this energy is small compared with the kinetic energies imparted to the fragments and the explosion products.

The following approach to an analytical evaluation of the restraining effect is by no means rigorous. The model it employs is that of a gas, initially at a very high pressure, expanding uniformly within the confines of a thin-walled cylindrical casing of infinite length. It does not consider any of the details of the detonation process. Although the model is not exact, it may provide a basis for evaluating the orders of magnitude of the various factors contributing to the final fragment velocities.

Consider first the conditions of velocity and pressure existing within the explosive gases. At any time t the velocity of the gases may be assumed to vary linearly from zero along the axis of the casing (r=0) to the value v_R adjacent to the casing (r=R), as given by

$$v = \frac{r}{R} v_R. \tag{1}$$

Since both v_R and R depend upon t, the gas velocity will depend upon both r and t.

In order for the gases to accelerate as they expand, a pressure gradient must exist which results in a net force acting radially outward on each element of gas volume, as illustrated in Figure 1. Equating this net force to the mass per unit length of the element times its radial acceleration results in

$$[p(r,t) - p(r + dr,t)] \, rd\theta = \left(\frac{\rho_c \pi R_o^2}{\pi R^2}\right) rdrd\theta \frac{d^2r}{dt^2} \tag{2}$$

where p(r,t) = pressure at radius r at time t,

ρ_c = initial mass density of the explosive,

R_o = initial radius of the casing.

[1] GURNEY, R. W. *The Initial Velocities of Fragments from Bombs, Shell, and Grenades.* U. S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Report No. 405, September 1943.

[2] THOMAS, L. H. U. S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Report No. 475.
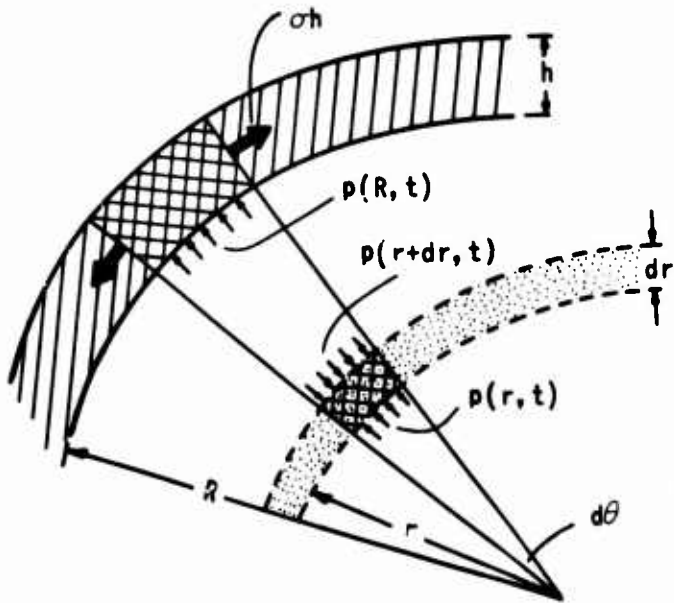
Figure I. FORCES ACTING WITHIN AN EXPLODING SHELL

Since

$$p(r + dr, t) = p(r,t) + \frac{\partial p}{\partial r} dr, \qquad (3)$$

Equation 2 becomes

$$- \frac{\partial p}{\partial r} = \frac{\rho_c R_o^2}{R^2} \frac{d^2 r}{dt^2} . \qquad (4)$$

This may be rewritten

$$- \frac{\partial p}{\partial r} = \rho_c \left(\frac{R_o}{R}\right)^2 \frac{dv}{dt} \qquad (5)$$

or

$$- \frac{\partial p}{\partial r} = \rho_c \left(\frac{R_o}{R}\right)^2 \left(\frac{\partial v}{\partial r} \frac{dr}{dt} + \frac{\partial v}{\partial R} \frac{dR}{dt}\right). \qquad (6)$$

From Equation 1

$$\frac{\partial v}{\partial r} = \frac{v_R}{R} \qquad (7a)$$

and

$$\frac{\partial v}{\partial R} = \frac{r}{R} \frac{dv_R}{dR} - \frac{r}{R^2} v_R. \qquad (7b)$$

Substituting in Equation 6,

$$- \frac{\partial p}{\partial r} = \rho_c R_o^2 \frac{v_R}{R^3} \frac{dv_R}{dR} r \qquad (8a)$$

or

$$- \frac{\partial p}{\partial r} = 2 \, f(R) r, \qquad (8b)$$

where $f(R)$ is defined by

$$f(R) \equiv \rho_c \frac{R_o^2}{2} \frac{v_R}{R^3} \frac{dv_R}{dR}. \qquad (9)$$

Equation 8b can be integrated to give

$$p(r,t) = p(o,t) - f(R) r^2. \qquad (10)$$

In order to evaluate the term $p(o,t)$, the equation of state for the adiabatically expanding gases is taken to be

2

$$P_{av} \; V^{\gamma} = P_o \; V_o^{\gamma} \tag{11a}$$

or
$$P_{av} \; R^{2\gamma} = P_o \; R_o^{2\gamma}, \tag{11b}$$

where V = instantaneous gas volume,

V_o = initial gas volume,

P_o = pressure the instant after detonation,

P_{av} = an average pressure within the casing, which is taken to be the average of $p(o,t)$ and $p(R,t)$ or, from Equation 10

$$P_{av} = p(o,t) - 1/2 \; f(R) \; R^2. \tag{12}$$

Combining Equations 11 and 12 and substituting for $p(o,t)$ in Equation 10

$$p(r,t) = P_o\left(\frac{R_o}{R}\right)^{2\gamma} - \frac{1}{2} \; f(R)r^2. \tag{13}$$

Hence, the pressure acting against the casing is

$$p(R,t) = P_o\left(\frac{R_o}{R}\right)^{2\gamma} - \frac{1}{2} \; f(R)R^2. \tag{14}$$

The internal pressure given by Equation 14 produces a tensile stress in the cylindrical casing which opposes the expansive effect of the pressure. The forces acting per unit length on an element of the casing are shown in Figure 1, where σ is the tensile stress resisting the influence of the internal pressure. The sum of the radial components of these forces may be set equal to the mass of the casing element times its radial acceleration. Thus,

$$p(R,t)Rd\theta - \sigma h d\theta = \rho_M h R d\theta \; \frac{d^2R}{dt^2} \tag{15}$$

where h = instantaneous thickness of the casing,

ρ_M = mass density of the casing material.

Conservation of volume requires that

$$h = \left(R_o/R\right)h_o, \tag{16}$$

where h_o is the initial thickness of the casing. Substituting for $p(R,t)$ from (14), Equation 15 may be written

3

$$p_o R_o^{2\gamma} R^{-(2\gamma - 1)} - \frac{1}{4} \rho_c R_o^2 \, v_R \frac{dv_R}{dR} - \sigma h_o \frac{R_o}{R} = \rho_M h_o R_o v_R \frac{dv_R}{dR}. \tag{17}$$

Johnson et al[3] have studied the stress-strain relationship for several metals during high deformation rates and report basically two types of behavior: (1) the stress-strain curve is similar to that found in a conventional or static tensile test but with a rate of work hardening roughly twice the static value; and (2) the stress jumps immediately to a high value in excess of the static tensile strength and remains constant thereafter, independent of the strain. For the first case a relationship of the form

$$\sigma = \sigma_o \epsilon^n \tag{18}$$

may be assumed where

$$\epsilon = \ln \frac{R}{R_o} \tag{19}$$

and σ_o and n may be taken to be twice their static values. The second case would be described by

$$\sigma = U \tag{20}$$

where U may be estimated as three times the conventional ultimate tensile strength. Normally n is expected to decrease with increasing strain rate, contrary to the above report. However, the behavior described by Johnson et al will be considered since it represents a more extreme situation and will yield a conservatively high estimate of the deformation energy.

For the first case (17) becomes

$$p_o R_o^{2\gamma} R^{-(2\gamma - 1)} - \frac{1}{4} \rho_c R_o^2 \, v_R \frac{dv_R}{dR} - \sigma_o \left(\ln \frac{R}{R_o} \right)^n h_o \frac{R_o}{R} = \rho_M h_o R_o v_R \frac{dv_R}{dR}, \tag{21}$$

which may be integrated directly to give

$$\frac{p_o R_o}{2(\gamma - 1)} \left[1 - e^{-2e(\gamma - 1)} \right] - \frac{\sigma_o h_o}{n + 1} \epsilon^{n + 1} = \frac{1}{2} \left(\rho_M h_o + \frac{1}{4} \rho_c R_o \right) v_R^2. \tag{22}$$

Similarly the second case becomes, after integration,

$$\frac{p_o R_o}{2(\gamma - 1)} \left[1 - e^{-2\epsilon(\gamma - 1)} \right] - U h_o \epsilon = \frac{1}{2} \left(\rho_M h_o + \frac{1}{4} \rho_c R_o \right) v_R^2. \tag{23}$$

Multiplying by $2\pi R_o$ both Equations 22 and 23 can be put in the form

[3]JOHNSON, R.C., STEIN, B. A., and DAVIES, R. S. *Basic Parameters of Metal Behavior Under High Rate Forming.* Arthur D. Little, Inc., Contract DA-19-020-ORD-5239, Fifth Interim Report to U. S. Army Materials Research Agency, WAL TR 111.2/20-4, April 1962 - June 1962.

$$\frac{1}{2}\left(M + \frac{1}{2} C\right)v_R^2 = \left\{\frac{p_o}{\rho_c(\gamma - 1)}\left[1 - e^{-2\epsilon(\gamma - 1)}\right] - \frac{2\sigma'}{\rho_c}\frac{h_o}{R_o}\epsilon\right\}C, \tag{24}$$

where M = the mass of the casing,

C = the mass of the explosive,

$$\sigma' = \frac{\sigma_o \epsilon^n}{n + 1} \qquad \text{for } \sigma = \sigma_o \epsilon^n$$

$$\sigma' = U \qquad \text{for } \sigma = U.$$

Gurney's formula is identical in form:

$$\frac{1}{2}\left(M + \frac{1}{2} C\right)v^2 = EC, \tag{25}$$

where v is the ultimate velocity of the casing and E is the energy per unit mass of explosive ultimately converted to the kinetic energies of the casing and the explosive gases. Equation 24 may be rewritten

$$\frac{1}{2}\left(M + \frac{1}{2} C\right)v_R^2 = EC, \tag{26}$$

where E is the energy per unit mass of explosive which has actually been converted to kinetic energy as a function of time. Thus,

$$E = \frac{p_o}{\rho_c(\gamma - 1)}\left[1 - e^{-2\epsilon(\gamma - 1)}\right] - \frac{2\sigma'}{\rho_c}\frac{h_o}{R_o}\epsilon, \tag{27}$$

and for long times

$$E = E. \tag{28}$$

The first term in Equation 27 is the contribution of the internal gas pressure to the kinetic energies of the casing and explosive gases. It increases with strain (and hence time) and approaches a final limiting value at large values of the strain. At a strain of 0.7 the casing and gases should have achieved over 90 percent of their final kinetic energies. This is exactly the strain (or time) dependence predicted by Thomas (Ref. 2, Equation 5.7). In reality, however, a final limiting value is probably reached at an earlier stage than anticipated from (27) since, when the casing fractures (or shortly thereafter), the effectiveness of the expanding gases will be reduced due to the gases escaping around the fragments. Hence the kinetic energy actually derived from the internal gas pressure will be less than that computed from (27).

The second term in (27) is a negative contribution to the kinetic energy arising from the resistance of the casing to plastic flow. As would be expected this term is larger for small-diameter, thick-walled casings, i.e., larger values of h_o/R_o. Furthermore, since

$$\frac{h_o}{R_o} = 2\frac{\rho_M/\rho_c}{C/M}, \tag{29}$$

5

the resistance to plastic flow has a greater effect when the charge:mass ratio is low. The term increases continuously as the strain increases, implying that if the casing were capable of expanding indefinitely without breaking, its kinetic energy would eventually revert entirely to energy of deformation and the expansion of the casing would cease. In reality, however, even ductile casing materials will fracture before the radius has expanded to 1-1/2 times its initial size (corresponding to a strain of about 0.4).

The extent to which the resistance of the casing to plastic flow detracts from the energy available from the expanding gases may be seen in Table I for both types of stress-strain behavior. Here are tabulated, for various values of the strain ϵ, the two terms appearing in Equation 27 computed for three different size casings and two values of the initial gas pressure. The casing material is taken to be AISI 1060 steel, quenched and tempered at 1200 F, for which the following constants apply:

$$\sigma_0 = 3.7 \times 10^5 \text{ psi*}$$

$$n = 0.3*$$

$$U = 400,000 \text{ psi}\dagger$$

$$\rho_M = 0.28 \text{ lb/cu in.}$$

Table I. CONTRIBUTIONS TO THE KINETIC ENERGY OF AN EXPLODING CASING

ϵ	Energy Contribution from Internal Pressure (in-lb) P_0 (psi)		Negative Energy Contribution from Resistance to Plastic Flow (in-lb)					
			$\sigma = \sigma_0\epsilon^n$ R_0/h_0			$\sigma = U$ R_0/h_0		
	3×10^6	2×10^6	10	5	3	10	5	3
0.01	3.7×10^8	2.5×10^8	0.01×10^8	0.02×10^8	0.03×10^8	0.01×10^8	0.03×10^8	0.04×10^8
0.05	17.6	10.7	0.08	0.15	0.25	0.07	0.13	0.20
0.1	32.3	21.6	0.18	0.36	0.60	0.13	0.26	0.39
0.2	55.0	36.6	0.45	0.89	1.49	0.26	0.53	0.79
0.3	71.0	47.4	0.76	1.51	2.52	0.39	0.79	1.18
0.04	82.3	54.8	1.10	2.20	3.67	0.53	1.05	1.58
Fracture —	—	—	—	—	—	—	—	—
0.5	(90.2)	(60.2)	1.10	2.20	3.67	0.53	1.05	1.58
0.6	(95.8)	(63.8)	1.10	2.20	3.67	0.53	1.05	1.58
0.7	(99.7)	(66.4)	1.10	2.20	3.67	0.53	1.05	1.58
∞	(109.)	(72.6)	1.10	2.20	3.67	0.53	1.05	1.58

---

*Two times static test values.

$\dagger$Three times static test value.

The explosive was considered to be Composition B, for which the following constants were assumed:

$$\rho_c = 0.061 \text{ lb/cu in}$$

$$\gamma = 2.75$$

$$p_0 = 3 \times 10^6 \text{ psi (Case 1)}$$

$$p_0 = 2 \times 10^6 \text{ psi (Case 2).}$$

It must be realized that the negative contribution to the kinetic energy due to the resistance to plastic flow can get no larger than those values which correspond to the strain at the time of fracture. Hence, the maximum energy absorbed would be that associated with the maximum attainable strain, i.e., $\epsilon = 0.4$. Table I is representative of casings exhibiting this ductile-type behavior. Brittle casings would fracture at a much lower value of strain and would therefore absorb considerably less energy than ductile casings. Thus, from Table I, a brittle casing which might fracture at a strain of 0.1 would absorb less than 25 percent of the energy a ductile casing would absorb.

Even for the most unfavorable conditions, namely a thick-walled ductile casing ($R_0/h_0 = 3$); the lowest initial pressure considered to be reasonable ($p_0 = 2 \times 10^6$ psi); and the stress-strain behavior described by Equation 18, the detrimental influence of the energy of deformation amounts to less than 7 percent of the energy contributed by the internal gas pressure *up to the instant of fracture.* In reality, the gases may continue to effectively accelerate the fragments even after fracture has occurred, making the values given in Table I for the energy contributed by the internal pressure valid beyond the point of fracture. Thus, the energy of deformation would negate an even smaller percentage than the previously cited energy derived from the gas pressure. Furthermore, a 7 percent change in the energy available produces just slightly more than 2.5 percent change in the fragment velocities. Such a small difference could easily go undetected or could be attributed to other variables in an actual fragmentation test.

The fragment velocity is plotted in Figure 2 as a function of radius, strain, or time (all are related) for a charge:mass ratio equal to one (corresponding to R_0/h_0 equal to about 10) and an initial pressure of 2×10^6 psi. The ultimate velocity agrees favorably with that calculated from Gurney's formula, where $E = 55.7 \times 10^8$ inch-pounds for Composition B. Better agreement could be obtained by suitable adjustments in p_0 and/or γ, but such manipulations are probably not meaningful in view of the approximations and assumptions already employed.

The conclusion to be drawn is that the resistance of the casing to plastic flow causes only minor attenuations in the fragment velocities. The energy attenuation is inversely proportional to the ratio of the shell radius to wall thickness, and amounts to a reduction of about 2.5 percent in the fragment velocities when the value of this ratio is as low as three.
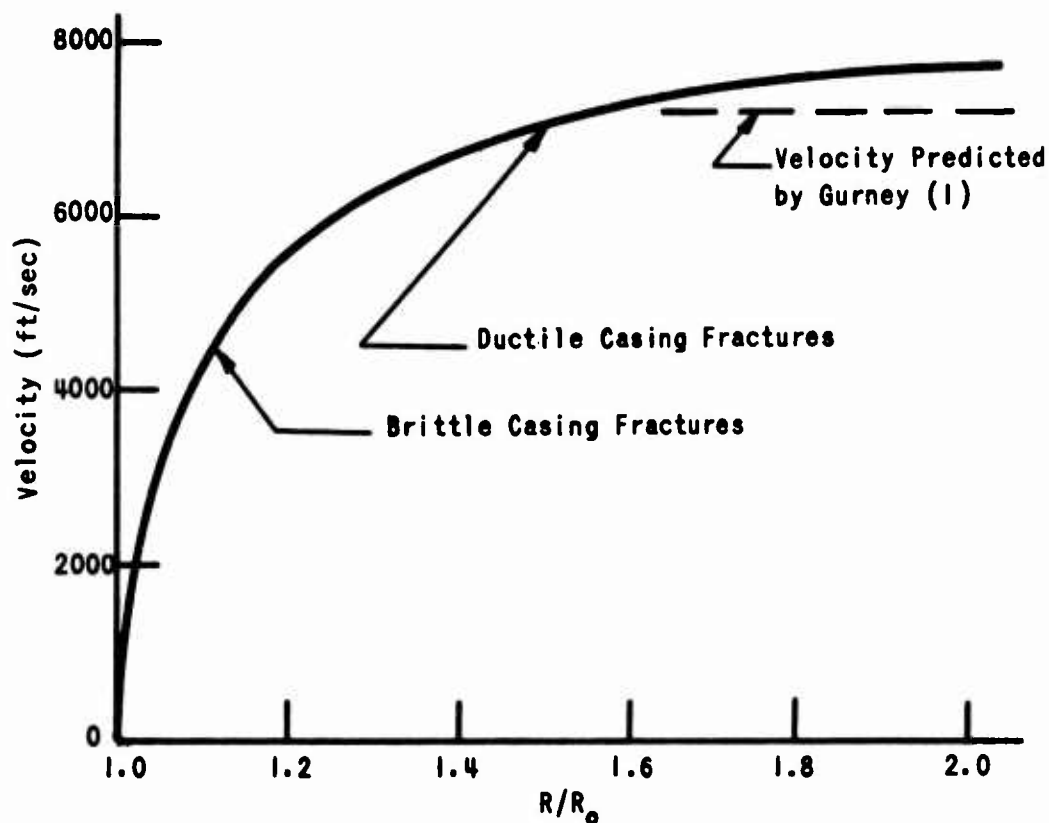
Figure 2. VELOCITY ACQUIRED BY SHELL CASING DURING ITS
EXPANSION ($C/M = 1$; $p_o = 2 \times 10^6$ psi)

It is interesting to note the difference in fragment velocities at the time of fracture for ductile and brittle casings. The ductile casing is already quite close to its ultimate velocity when fracture occurs, whereas the fragments from the brittle casing must increase their velocities by nearly 75 percent in order to achieve the same velocity. This disparity could be overcome if the explosive gases were to continue to accelerate the fragments after fracture in spite of a tendency for the gases to escape through the spaces between the fragments. The requisite forces could be derived both from a normal component due to the retained internal pressure and from a shear component resulting from the drag forces of the escaping gas. Gurney[4] has made some quantitative calculations which support this point of view.

---

[4]GURNEY, R. W. U. S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Report No. 635.

U. S. ARMY MATERIALS RESEARCH AGENCY
WATERTOWN, MASSACHUSETTS 02172

TECHNICAL REPORT DISTRIBUTION

Report No.: AMRA TR 66-33   Title: Attenuation of Fragment Velocities Due
            October 1966   to the Deformation Resistance of the
                                        Casing

No. of Copies	To
	Office of the Director, Defense Research and Engineering, The Pentagon, Washington, D. C. 20301
1	ATTN: Dr. Earl T. Hayes, Assistant Director (Materials)
20	Commander, Defense Documentation Center, Cameron Station, Building 5, 5010 Duke Street, Alexandria, Virginia 22314
1	Defense Metals Information Center, Battelle Memorial Institute, Columbus Ohio 43201
	Headquarters, Department of the Army, Office Chief of Research and Development, Physical Sciences Division, Washington, D. C. 20310
2	ATTN: Chief, Chemistry and Materials Branch
	Commanding Officer, Army Research Office (Durham), Box CM, Duke Station, Durham, North Carolina 27706
1	ATTN: Information Processing Office
	Commanding General, U. S. Army Materiel Command, Washington, D. C. 20315
1	ATTN: AMCRD-RC-M
	Commanding General, Deseret Test Center, Fort Douglas, Utah 84113
1	ATTN: Technical Information Office
	Commanding General, U. S. Army Missile Command, Redstone Arsenal, Alabama 35809
1	ATTN: Technical Library
	Commanding General, U. S. Army Munitions Command, Dover, New Jersey 07801
1	ATTN: Technical Library
	Commanding General, U. S. Army Natick Laboratories, Natick, Massachusetts 01762
1	ATTN: Technical Library
	Commanding General, U. S. Army Weapons Command, Rock Island, Illinois 61202
1	ATTN: Technical Library

No. of Copies	To

Commanding General, White Sands Missile Range, New Mexico 88002
1 ATTN: STEWS-WS-VT

Commanding Officer, Aberdeen Proving Ground, Maryland 21005
1 ATTN: Technical Library, Building 313

Commanding Officer, Frankford Arsenal, Bridge and Tacony Streets,
Philadelphia, Pennsylvania 19137
1 ATTN: Library Branch C 2500

Commanding Officer, Harry Diamond Laboratories, Connecticut Avenue and
Van Ness Street, N. W., Washington, D. C. 20438
1 ATTN: Technical Information Office

Commanding Officer, Department of the Army, Ohio River Division
Laboratories, Corps of Engineers, 5851 Mariemont Avenue,
Cincinnati, Ohio 45227
1 ATTN: ORDLB-TR

Commanding Officer, Picatinny Arsenal, Dover, New Jersey 07801
1 ATTN: SMUPA-VA6

Commanding Officer, Redstone Scientific Information Center,
U. S. Army Missile Command, Redstone Arsenal, Alabama 35809
4 ATTN: AMSMI-RBLD, Document Sec.

Commanding Officer, Watervliet Arsenal, Watervliet, New York 12189
1 ATTN: SWEWV-RDT, Technical Information Services Office

1 Commanding Officer, U. S. Army Aviation Materiel Laboratories,
Fort Eustis, Virginia 23604

Commanding Officer, Ballistics Research Laboratory, Aberdeen Proving Ground,
Maryland 21005
1 ATTN: Chief, Terminal Ballistics Section

Commanding Officer, USACDC Ordnance Agency, Aberdeen Proving Ground,
Maryland 21005
2 ATTN: Library, Building 305

Commanding Officer, U. S. Army Combat Developments Command,
Fort McClellan, Alabama 36201
1 ATTN: C-B-R Agency

Commanding Officer, U. S. Army Engineer Waterways Experiment Station,
Vicksburg, Mississippi
1 ATTN: Research Center Library

No. of Copies	To
	Director, Naval Research Laboratory, Anacostia Station, Washington, D. C. 20390
1	ATTN: Technical Information Officer
	Chief, Office of Naval Research, Department of the Navy, Washington, D. C. 20315
1	ATTN: Code 423
	Headquarters, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio 45433
5	ATTN: ASRCEE
1	U. S. Atomic Energy Commission, Office of Technical Information Extension, P. O. Box 62, Oak Ridge, Tennessee 37830
	National Aeronautics and Space Administration, Washington, D. C. 20546
1	ATTN: Mr. B. G. Achhammer
1	Mr. G. C. Deutsch
1	Mr. R. V. Rhode
	National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama 35812
1	ATTN: R-P&VE-M, Dr. W. R. Lucas
1	M-F&AE-M, Mr. W. A. Wilson, Building 4720
	Commanding Officer, U. S. Army Materials Research Agency, Watertown, Massachusetts 02172
5	ATTN: AMXMR-AT
1	AMXMR-AX
1	AMXMR-RP
1	AMXMR-RX
1	Author
70	TOTAL COPIES DISTRIBUTED

No. of Copies	To

Director, Naval Research Laboratory, Anacostia Station, Washington, D. C. 20390
1 ATTN: Technical Information Officer

Chief, Office of Naval Research, Department of the Navy, Washington, D. C. 20315
1 ATTN: Code 423

Headquarters, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio 45433
5 ATTN: ASRCEE

1 U. S. Atomic Energy Commission, Office of Technical Information Extension, P. O. Box 62, Oak Ridge, Tennessee 37830

National Aeronautics and Space Administration, Washington, D. C. 20546
1 ATTN: Mr. B. G. Achhammer
1   Mr. G. C. Deutsch
1   Mr. R. V. Rhode

National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama 35812
1 ATTN: R-P&VE-M, Dr. W. R. Lucas
1   M-F&AE-M, Mr. W. A. Wilson, Building 4720

Commanding Officer, U. S. Army Materials Research Agency, Watertown, Massachusetts 02172
5 ATTN: AMXMR-AT
1   AMXMR-AX
1   AMXMR-RP
1   AMXMR-RX
1   Author

70 TOTAL COPIES DISTRIBUTED

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		

1. ORIGINATING ACTIVITY *(Corporate author)*	2a. REPORT SECURITY CLASSIFICATION
U. S. Army Materials Research Agency Watertown, Massachusetts 02172	Unclassified
	2b. GROUP

3. REPORT TITLE

ATTENUATION OF FRAGMENT VELOCITIES DUE TO THE DEFORMATION RESISTANCE OF THE CASING

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

Bruggeman, Gordon A.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1966	8	4

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. D/A 1C024401A110	AMRA TR 66-33
c. AMCMS Code 5025.11.842	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d. Subtask 35932	

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Materiel Command Washington, D. C. 20315

13. ABSTRACT

Estimates are made of the energy required to expand an exploding shell casing relative to the kinetic energies of the fragments. It is shown that the energy of deformation detracts very little from the ultimate fragment velocities. (Author)

DD FORM 1473 1 JAN 64

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fragment velocities						
Energy of deformation						
Shell casings						
Terminal ballistics						
Ammunition fragments						
Fragmentation tests						
Terminal velocities						
Explosion effects						
Explosion gases						
Plasticity						
Tensile properties						
Deformation energy						
Dynamics						
Kinetic energy						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through

_____."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through

_____."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through

_____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.