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# Numerical simulations of the effect of blast and fragment impact on rod projectiles and shaped charges

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# Abstract

Numerical simulations were undertaken to investigate the possibility of effectiveness of using blast or fragment impacts as hard kill countermeasures against kinetic energy threats (tungsten rods at high velocity) and chemical energy threats (shaped charges). The results indicate that medium calibre (APFSDS-like) projectiles can be deflected or disrupted effectively by either blast or small fragment impact. Long rods (again APFSDS-like) are much harder to disrupt and the various approaches surveyed did not work. For shaped charge jets, premature detonation due to fragment impact is possible but there remains a non-negligible off-axis residual jet that must be stopped.

# Résumé

Des simulations numériques ont été effectuées afin de savoir si l'effet de souffle ou l'impact par des fragments pourrait être efficace comme moyen de protection contre des menaces à énergie cinétique (tiges en tungstène à haute vitesse) et à énergie chimique (charges creuses). On a constaté que la trajectoire d'un projectile de calibre moyen de type flèche pouvait être déviée ou perturbée par les deux contre-mesures. Un projectile de gros calibre de type flèche est beaucoup plus difficile à perturber et les contre-mesures étudiées n'ont pas fonctionné. Pour les charges creuses, une détonation prématurée par impact de fragment est possible, mais il reste un jet résiduel et létal.

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# Executive summary

For many armed forces, including Canada's, geopolitical realities have changed the operational requirements for armoured vehicles. The ability to rapidly deploy anywhere in the world has become very important and to do so, an air transportable fighting vehicle is needed. In practice, this means a light armoured vehicle (LAV) weight of around 20 tons versus around 55 tons for a main battle tank, the weight difference due mainly to lighter armour and/or active protection systems. At the same time, more lethal anti-vehicle weapons are being developed. The aim of the present study is to examine near-field explosive blast and high-speed fragments as active protection systems for a LAV. The study emphasizes the terminal ballistics aspects, i.e. the interaction between the threat and countermeasure.

Numerical simulations were undertaken to ascertain whether or not blast or fragment impacts are possibly useful as hard kill countermeasures against kinetic energy threats (APFSDS tungsten rods at high velocity) and chemical energy threats (shaped charge jets). The results indicate that medium calibre projectiles can be deflected or disrupted effectively by either blast or small fragment impact. Large calibre long rods are much harder to disrupt and the various approaches surveyed did not work. For shaped charge jets, premature detonation due to fragment impact is possible but there remains a non-negligible off-axis residual jet that must be stopped.

Grant W.J. McIntosh, 2005. Numerical simulations of the effect of blast and fragment impact on rod projectiles and shaped charges. DRDC Valcartier TN 2004-360 DRDC-Valcartier.

# Sommaire

Pour de nombreuses forces armées, dont celles du Canada, les réalités géopolitiques ont changé les conditions opérationnelles des véhicules blindés. La capacité de se déployer rapidement n'importe où dans le monde est devenue très importante et pour ce faire, un véhicule de combat transportable par avion est nécessaire. En pratique, cela signifie un véhicule blindé léger (VBL) d'environ 20 tonnes contre un char d'assaut d'environ 55 tonnes, la différence de poids due principalement au blindage plus léger et/ou à des systèmes de protection active. En même temps, des armes plus létales sont développées. Le but de la présente étude est d'examiner l'effet de souffle et les fragments à haute vitesse comme systèmes de protection actifs pour des VBL. L'étude souligne les aspects de balistique terminale, c.-à-d. l'interaction entre la menace et les contre-mesures..

Des simulations numériques ont été effectuées afin de savoir si l'effet de souffle ou l'impact par des fragments pourrait être efficace comme moyen de protection contre des menaces à énergie cinétique (type flèche en tungstène à haute vitesse) et à énergie chimique (charges creuses). On a constaté que la trajectoire d'un projectile de calibre moyen pouvait être déviée ou perturbée par les deux contre-mesures. Un projectile de gros calibre est beaucoup plus difficile à perturber et les contre-mesures étudiées n'ont pas fonctionné. Pour les charges creuses, une détonation prématurée par impact de fragment est possible, mais il reste un jet résiduel et létal.

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# Table of contents

# List of figures

# List of tables

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# 1. Introduction

For many armed forces, including Canada's, geopolitical realities have changed the operational requirements for armoured vehicles. The ability to rapidly deploy anywhere in the world has become very important and to do so, an air transportable fighting vehicle is needed. In practice, this means a light armoured vehicle (LAV) weight of around 20 tons versus around 55 tons for a main battle tank, the weight difference due mainly to lighter protection, whether passive armour or active protection systems. At the same time, more lethal anti-vehicle weapons are being developed. The aim of the present study is to examine near-field explosive blast and high-speed fragments as active protection systems for a LAV. The study emphasizes the terminal ballistics aspects, i.e. the interaction between the threat and countermeasure.

This work was done between March 2002 and October 2003 under Project 12fh, Investigation of Advanced Protection Systems for LAVs, WBE 12fh13.

## 2. Numerical simulations

Numerical simulations of various threat-countermeasure scenarios were undertaken using the hydrodynamic finite-element program LS-DYNA. Full three dimensional finite element studies were done for three possible threats: a short rod (9.67-cm long, 0.84-cm diameter) at 1400 m/s representing a typical medium caliber threat such as a APFSDS penetrator, a long rod (52.56-cm long, 2.4-cm diameter) penetrator at 1500 m/s typical of a large caliber 120-mm threat and a shaped charge (81mm BRL) at 800 m/s. The countermeasures examined were near field blast deflection and disruption and fragments.

The rods were meshed across their faces and then with evenly spaced slices along their respective lengths. The element geometry is shown in Figure 1 for the short rod (50 longitudinal slices). The long rod uses a scaled-up version of the same cross-sectional mesh but with 150 longitudinal slices.

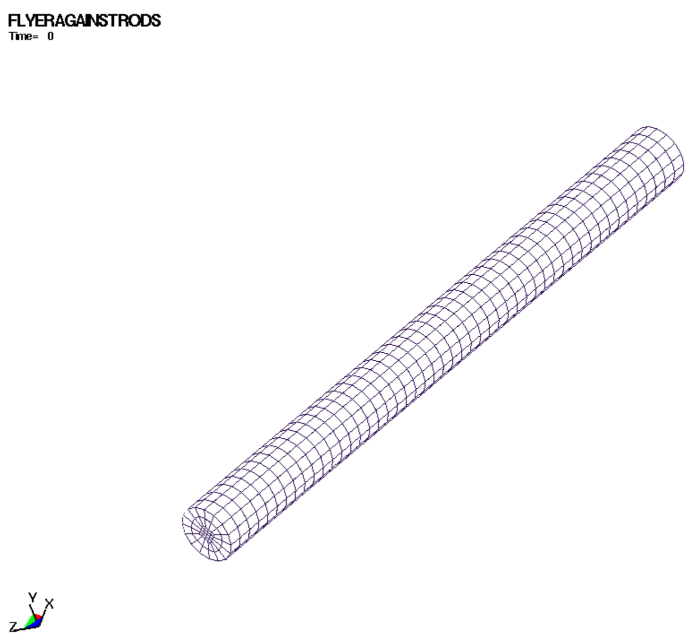


*Figure 1. Rod geometry for the short rod.*

The rods were modeled using an elastic-plastic material model for tungsten. The fragments were either steel or tungsten. The various properties used for these materials are shown in Tables I and II (from D.Nandlall, private communication). For the blast studies, the explosive used was detasheet. This was chosen as representative of a typical explosive. The overall conclusions should not depend too strongly on the type of explosive used.

*Table I. Steel properties*

| PARAMETER | VALUE |
|---|---|
| Density | 7.85 g/cm3 |
| Young's modulus | 1.975 Mbar |
| Poisson's ratio | 0.33 |
| Yield strength | 0.0132 Mbar |
| Tangent hardening modulus | 0.0181 |
| Hardening parameter | 1.0 |
| Failure Strain | 1.0 |

*Table II. Tungsten properties*

| PARAMETER | VALUE |
|---|---|
| Density | 17.7 g/cm3 |
| Young's modulus | 3.24 Mbar |
| Poisson's ratio | 0.303 |
| Yield strength | 0.0674 Mbar |
| Tangent hardening modulus | 0.00405 |
| Hardening parameter | 1.0 |
| Failure Strain | 2.0 |

# 3. Countermeasures for rod impacts

The first countermeasure to be considered is blast. To study this, simulations were undertaken of a small quantity of explosive (Detasheet) ignited close to the rods near the leading end. For these simulations, only three parameters – mass and shape of explosive and distance to rod – were changed. The center of the explosive was moved to various distances from the centerline of the long rod and at the time of ignition was about 15 cm along the long rod away from the leading end. The expanding detonation products interacted with the moving rod and any deviation of trajectory or disruption of rod geometry was noted. For the long rods, very little disturbance was found and the rod continued practically undeviated (see Table III) to the typical armour of a light armoured vehicle (1.5 cm of RHA) with subsequent perforation.

*Table III Center of mass velocity deviations by explosive blasts of a long rod*

| Center-to-center distance | 2.5 cm cube | 5.0 cm cube | 2.5 cm dia. | 5.0 cm dia. |
|---|---|---|---|---|
| 6 cm | 0.11° | 0.50° | 0.029° | 0.23° |
| 12 cm | 0.046° | 0.42° | 0.024° | 0.19° |
| 18 cm | 0.042° | 0.42° | 0.022° | 0.15° |

Fewer cases for the short rod were tried, but in general, the rod became yawed relative to its initial trajectory and was severely limited in its performance on the backing. This is shown in Figure 2. The deviation of the center-of-mass trajectory was not recorded, as the yaw effect was more important.

The second countermeasure considered was fragment impact. A 2.5-cm square, 0.5-cm thick fragment impacting with a trajectory normal to the rods at 1000 or 2000 m/s was simulated. Tungsten and steel fragments were tried. For the long rod, only a tungsten fragment at 2000 m/s had a significant effect and caused some deformation of the rod, as shown in Figure 3. Steel fragments had a relatively minor effect. For the short rod, any fragment impact causes major disruption by inducing a rotation of the rod, even a steel fragment at 1000 m/s. The angular velocity imparted to the rod is naturally a function of both the velocity and the point of impact of the fragment relative to the center of mass of the projectile. Kinematic considerations, primarily conservation of momentum, show that there cannot be a large change in the direction of the center of mass of the incoming projectile unless the momentum of the fragment is a significant fraction of the momentum of the incoming projectile. The long rod at 1500 m/s has a momentum of 6.31e8 g-cm/s and a tungsten fragment at 2000 m/s, 1.1e7 g-cm/s (1.7% of the long rod's). The short rod at 1400 m/s has a momentum of 1.33e7 g-cm/s whereas a steel fragment at 1000 m/s has a momentum of 2.45e6 g-cm/s (18% of the short rod's). A summary of the changes of center of mass velocity for various scenarios is given in Table IV. Fragment impact occurred at the midpoint of the rods.

*Table IV. Center of mass velocity deviations for various fragments*

| TARGET | FRAGMENT MATERIAL | FRAGMENT VELOCITY | DEVIATION |
|---|---|---|---|
| Long rod | RHA | 1000 m/s | 0.13° |
| Long rod | RHA | 2000 m/s | 0.23° |
| Long rod | Tungsten | 1000 m/s | 0.54° |
| Long rod | Tungsten | 2000 m/s | 0.69° |
| Short rod | RHA | 1000 m/s | 3.1° |
| Short rod | RHA | 2000 m/s | 4.3° |
| Short rod | Tungsten | 1000 m/s | 9.9° |
| Short rod | Tungsten | 2000 m/s | 10.8° |

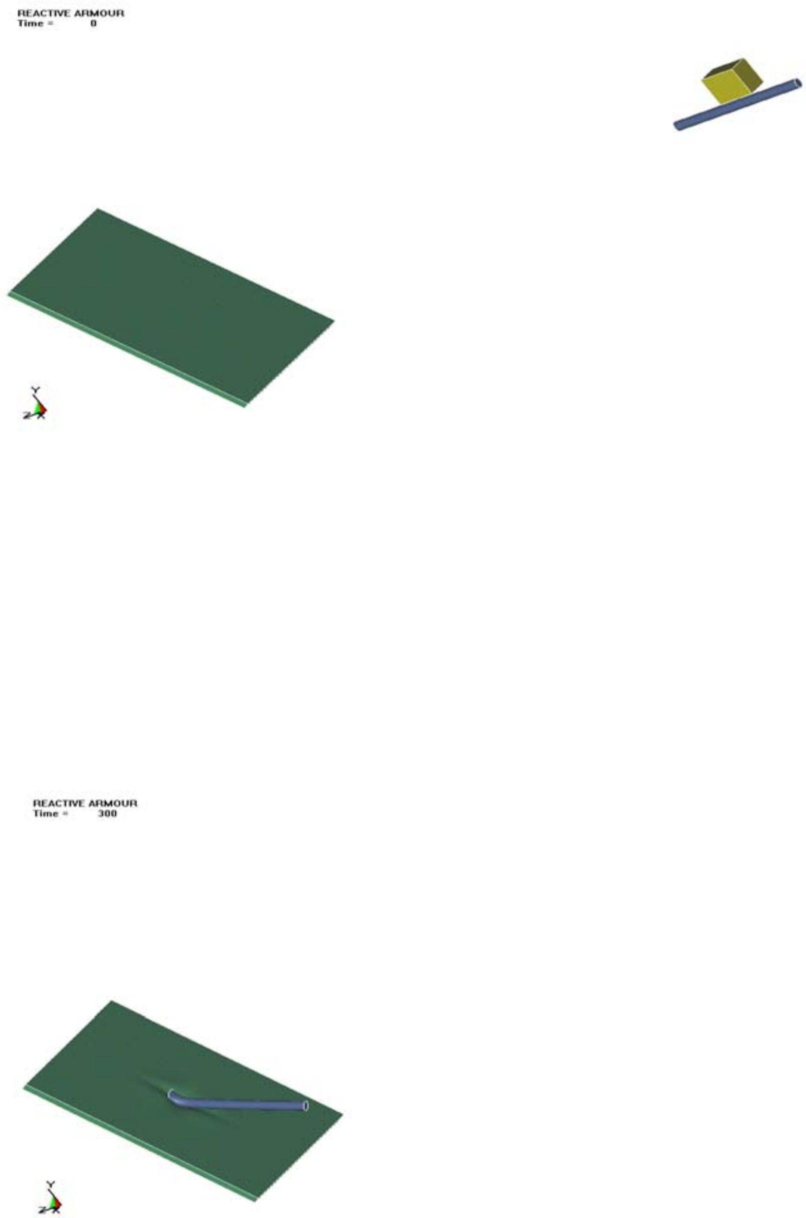


*Figure 2  Yaw and bending of a short rod by a near field blast*

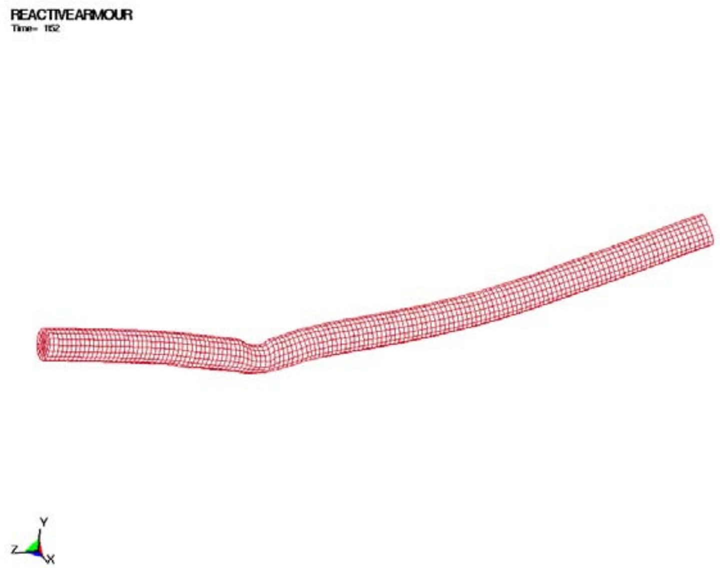


*Figure 3. Distortion of a long rod 1152 microseconds after fragment impact*

# 4. Protection against shaped charge attacks

Light passive armour alone cannot stop a shaped charge jet. One means of protection is to disrupt the charge before it detonates at its designed stand-off distance. Schemes have been suggested such as a fragment impact on the shaped charge to perforate the explosive and liner [1], but the charge still detonates normally and the imperfect jet that forms is still capable of penetrating light armoured vehicles. Another scheme is to prematurely detonate the charge by fragment impact at distances much greater than the usual standoff distance. This can be evaluated approximately using empirical relationships based upon explosive detonation thresholds for a given fragment mass and velocity. Full shock to detonation calculations can be undertaken in borderline cases. As an example of this later case, a 0.5-cm steel cube at 1000 m/s was launched against a TNT filled shaped charge warhead. The shock to detonation transition was modeled using the Lee-Tarver model [2] with the parameters for the explosive properties given in Table V. The impact causes an off-axis detonation starting at the point of impact. In Figure 4, the resulting expansion of the detonation products and collapse of the shaped charge warhead liner is shown. The first image (upper left) shows the scenario before impact. The second (upper right) shows the expanding detonation products (the casing is not displayed) and the third image (lower left) shows an imperfect, off-axis - but still lethal – jet is clearly forming (the detonation products are not shown). A final scheme, shaped charge jet attack on an incoming shaped charge warhead, was not examined numerically as it is already well known from experiments that it will work [3]

*Table V. TNT explosive properties*

| PARAMETER | VALUE |
|---|---|
| Density | 1.645 g/cm**3 |
| Shear modulus | 0.0256 MBar |
| Yield strength | 0.0001 MBar |
| Hardening modulus | 0 |
| Pressure cutoff | 0 |
| JWL A parameter for reaction products | 33.94889 MBar |
| JWL B parameter for reaction products | 0.821662 MBar |
| JWL XP1 parameter for reaction products | 8.3 |
| JWL XP2 parameter for reaction products | 2.8 |
| Ignition unburned fraction rate exponent | 0.667 |
| JWL G for reaction products | 0.6e-5 |
| JWL R1 parameter for unreacted explosive | 171.01 |
| JWL R2 parameter for unreacted explosive | -0.03745 |
| JWL R3 parameter for unreacted explosive | 1.5344e-5 |
| JWL R5 parameter for unreacted explosive | 9.8 |
| JWL R6 parameter for unreacted explosive | 0.98 |
| Ignition fraction upper limit | 0.03 |
| Ignition reaction rate | 50 |
| Growth reaction rate | 360. |
| Growth pressure rate exponent | 1.2 |
| Growth burned fraction rate exponent | 0.667 |
| Growth unburned fraction rate exponent | 1.0 |
| Heat capacity of reaction products | 1e-5 |
| Heat capacity of unreacted explosive | 2.7172e-5 |
| Ignition compression rate exponent | 4.0 |
| Critical compression fraction | 0.0 |
| Heat of reaction | 0.058 |
| Initial temperature | 298. C |
| Completion reaction rate | 0. |
| Completion burned fraction rate exponent | 0.0 |
| Completion unburned fraction rate exponent | 0. |
| Completion pressure rate exponent | 0.0 |
| Growth fraction upper limit | 1.0 |
| Completion fraction lower limit | 1.0 |

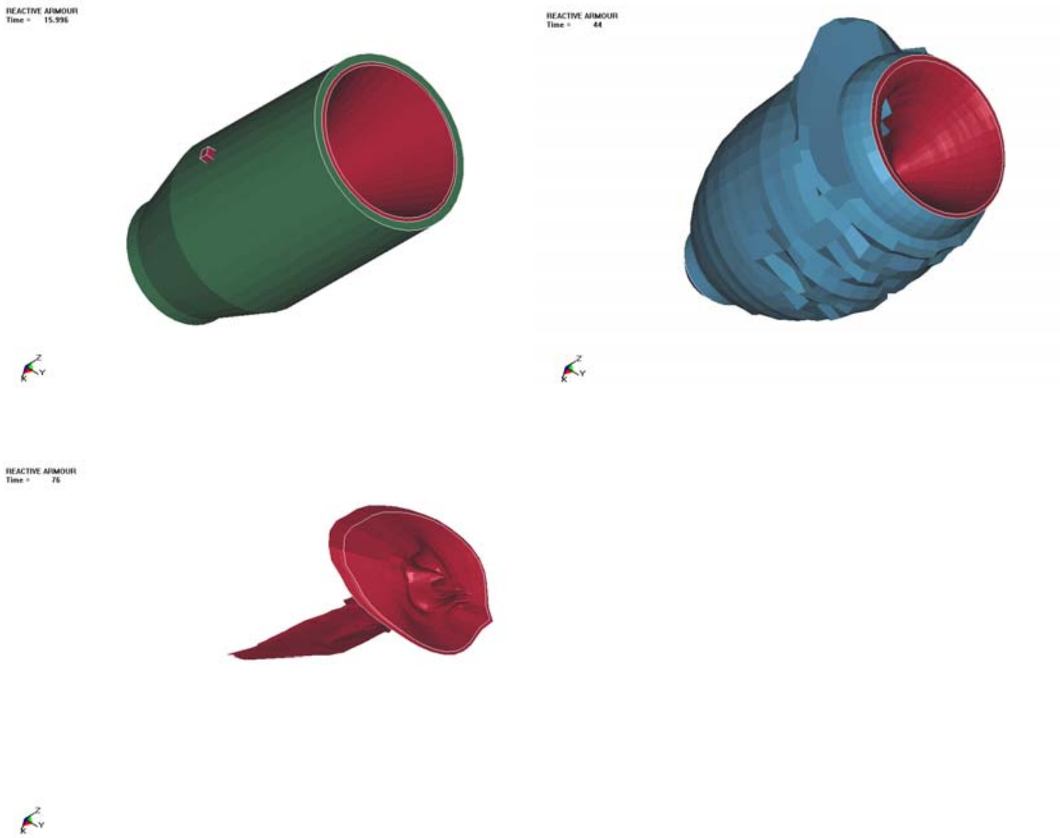


*Figure 4. Off-axis jet formation by premature detonation due to fragment impact: at 0, 28, 60 microseconds after impact*

# 5. Conclusions

Protection of a light armoured vehicle against typical projectiles of medium caliber is possible using a variety of means. The simulations indicate that protection against the medium calibre rod penetrator can be achieved using fragments and near field blast. Against a large calibre long rod projectile, of the systems considered, only a high-speed tungsten fragment showed any promise. The other fragments and blast mechanisms did not disrupt the long rods sufficiently to provide adequate protection. Against a shaped charge, premature detonation is possible but an imperfect jet is still formed. Whether or not a practical implementation of these protection systems can be achieved is an open question.

# 6. References


1. Chanteret, P.Y., "Effect of Fragment Impact on Shaped Charge Functioning", 19th International Symposium of Ballistics, 7-11 May 2001, Interlaken, Switzerland, p.599-605

2. Green, L.G., Tarver, C.M., Erskine, D.J. "Reaction Zone Structure in Supracompressed Detonating Explosives", 9th Symposium on Detonation (International), pp.670-682

3. Armour Concept Demonstration Program, Final Contractor Report of the Bendix Avelex Inc., May 1990, Confidential,DSS Contract #W8477-B-CB33/01-SV

# List of symbols/abbreviations/acronyms/initialisms

| | |
|---|---|
| APFSDS | Armour Piercing Fin Stabilized Discarding Sabot |
| LAV | Light Armoured Vehicle |

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Numerical simulations were undertaken to investigate the possibility of effectiveness of using blast or fragment impacts as hard kill countermeasures against kinetic energy threats (tungsten rods at high velocity) and chemical energy threats (shaped charges). The results indicate that medium calibre (APFSDS-like) projectiles can be deflected or disrupted effectively by either blast or small fragment impact. Long rods (again APFSDS-like) are much harder to disrupt and the various approaches surveyed did not work. For shaped charge jets, premature detonation due to fragment impact is possible but there remains a non-negligible off-axis residual jet that must be stopped.

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