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MELBOURNE, VICTORIA

TECHNICAL NOTE

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BALLISTIC EVALUATION OF APPLIQUE ARMOURS - PRESENTATION AND INTERPRETATION OF BALLISTIC DATA

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ABSTRACT

Techniques of carrying out armour evaluations are reviewed. Attention is given to methods of comparison which use the residual penetration into a reference block, a method which is particularly useful with applique armours. It is shown how such data can be represented in terms of weight per unit area, and combined with velocity/range data to show the ranges at which armours are defeated as a function of weight.

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CONTENTS

BALLISTIC EVALUATION OF APPLIQUE ARMOURS - PRESENTATION AND INTERPRETATION OF BALLISTIC DATA

1. INTRODUCTION

In the design of add-on or applique armour systems, cost and time militate against a full evaluation of V_{50} ballistic limit data for each possible combination of materials. The complexity and multitude of both material and geometric options requires a systematic approach to achieve optimization with a limited testing program. For this reason sampling techniques have been developed where as little as one shot is sufficient to indicate the merit of a target configuration.

A convenient sampling technique is to fire the projectile through the array to be assessed and judge the performance by the depth of residual penetration into a witness pack. ~~Yaziv,~~ Rosenberg and Partom [1], showed that using this method it is possible to produce merit ratings which rank armours in terms of weight saved. In this report, performance assessment methods are reviewed with particular attention being given to the method of Yaziv et al. [1]. Typical firing data is presented in graphical form and the technique is extended using projectile velocity/range data to allow a calculation of the range at which protection is achieved. In this form ballistic data is more easily assessed in terms of the statement of threat. AUSTRALIA. (JES)

2. ASSESSMENT OF MERIT

Conventionally, performance of armour is assessed by the comparison of its ballistic limit with that of a standard armour. Such methods have been reviewed in detail by Mascianica [2]. The most used criterion is a V_{50} PBL (Protection Ballistic Limit) which is the velocity at which fifty percent of impacts would result in complete perforation and fifty percent in non-perforation of a witness panel placed behind the target. Other ratings are also available such as θ_{50} where an angle for defeat at a standard velocity is used.

The performance of an armour for mobile structures must be measured in terms of weight while applicability will depend on other aspects such as cost, durability and serviceability. In terms of assessing performance for a specified level of protection the weight parameter of most use is the areal density which is the mass of armour per unit area. For a single homogeneous plate of material density ρ, thickness h, angle of impact obliquity θ, the areal density, A, is

$$A = \rho h \sec\theta \tag{1}$$

Where multiple plates are employed the total areal density is simply the sum of the component areal densities. Clearly, to minimize weight the lowest areal density possible is sought.

Merit ratings of an armour are specified in terms of velocity or weight. Thus the velocity merit rating (VMR) is defined as the ratio of V_{50} PBL of a candidate to the V_{50} PBL of a standard armour of the same areal density,

$$VMR = \frac{V_{50} \text{ (Candidate)}}{V_{50} \text{ (Standard)}} \tag{2}$$

Similarly the weight merit rating (WMR) is defined in terms of areal density (A) for the same ballistic limit

$$WMR = \frac{A \text{ (Standard Armour)}}{A \text{ (Experimental Armour)}} \tag{3}$$

Both these forms give a result greater than unity for an experimental armour which outperforms the standard. Usually the standard will be rolled homogeneous armour (RHA). The determination of V_{50} ballistic limits is tedious, requiring a number of shots above and below the ballistic limit and within a specified velocity bracket. Clearly it is preferable if simpler sampling procedures can be found. Ipson and Recht [3] have shown how V_{50} ballistic limits can be accurately estimated from the impulse delivered to a ballistic pendulum. Although this method is very effective and conservative of shots it requires specialized facilities.

A more cost effective method of comparing performance is to measure the residual depth of penetration into a witness pack after perforation of a trial armour configuration. Such a test procedure is depicted in Fig. 1. If the witness pack is a reference material such as RHA, then there is some quantitative appreciation of the weight of steel saved for a particular configuration. Yaziv et al [1] have quantified the technique by defining a Differential Efficiency Factor (DEF) which is the weight of steel saved by an add-on element divided by the weight of the element itself. Consider the geometry of Fig. 1, where an applique armour is placed in front of the reference pack. Then

$$DEF = \frac{A_0 - A_x}{A_1} \qquad (4a)$$

Where A_0 is the areal density of the reference pack which can be defeated,

A_1 is the areal density of the applique, and

A_x is the areal density of the reference pack which is penetrated after interaction with the applique.

The DEF indicates the reduction in weight of a standard pack due to the application of the add-on armour, relative to the weight of the add-on armour itself. Thus a high DEF indicates an efficient applique. In terms of the densities of the applique and reference material, ρ_1 and ρ_0 respectively, the depths of penetration into the reference pack, P_O and P_x and the thickness of the applique P_1,

$$DEF = \frac{\rho_0 \; (P_0 - P_x)}{\rho_1 \; P_1} \qquad (4b)$$

where $A_0 = \rho_0 \; P_0$,
$A_1 = \rho_1 \; P_1$
and $A_x = \rho_0 \; P_x$

3. EXPERIMENTAL MEASUREMENT OF APPLIQUE PERFORMANCE

A series of firings were undertaken to demonstrate the usefulness of tests of the type illustrated in Fig. 1, where residual depth into a thick witness pack is measured. The pack was constructed of multiple 37 mm blocks of 5083 H115 aluminium placed back-to-back. The appliques chosen were single steel sheets of various thicknesses placed 240 mm in front of the witness pack. The steels chosen were of hardness equivalent to high hardness steel armour [4] and the tests were arranged to give normal impact on both the applique and the witness pack. A 12.7 mm armour piercing projectile was fired at the plates with impact at the measured muzzle velocity (V_0) of 850 ms^{-1}.

The results are presented in Fig. 2 as a plot of Depth of Penetration into the witness pack against the Weight per Unit Area of the applique. Applique thickness is indicated, together with weight per unit area, on the abscissa. The experimental data are plotted using either of two symbols depending on the failure mode of the steel applique. An oblique continuous line indicates the expected residual depth of penetration if the weight of the applique added is equal to the reduction in weight of aluminium perforated. This line is simply calculated by putting the Differential Efficiency Factor (DEF) in equation (4b) equal to unity which results in a simple straight line relationship between the reduced depth of penetration ($P_0 - P_x$) and the weight per unit area of add-on armour ($\rho_1 P_1$). The intercept, P_0, was experimentally established to be 75 mm by firing a reference shot without the applique, as in Fig. 1. Points below this oblique line indicate that an advantage is gained with the use of the applique, while points on or above the line indicate the applique is equivalent to, or worse than, an increased thickness of aluminium respectively.

Figure 2 also includes a horizontal dashed line representing a nominal armoured vehicle side thickness, taken as 50 mm of aluminium. If the purpose of the applique is to prevent perforation of this vehicle side by the particular 12.7 mm AP round at the muzzle velocity, then the weight of applique to be added can easily be judged by the position at which the experimental points fall below this dashed line. The weight of aluminium to be added to obtain the same result is judged by the position at which the oblique line crosses the horizontal line representing the vehicle side thickness. The advantage of using a reference material identical to that of the side of the vehicle is clear. If this is not possible, however, a representative vehicle side thickness is readily established by replacing the applique, in the test configuration of Fig. 1, by a sample of the vehicle side for a single shot. A value for ($P_0 - P_x$) is then established as the "effective" vehicle side thickness for the purpose of the present analysis.

The scatter of results in Fig. 2 gives some indication of the confidence with which the up-armouring can be performed. Generally, but not always, better performance was achieved in the present tests where the steel applique failed by discing, because this led to greater induced tumbling of the projectile. Thus whilst ideally a single shot should give a good indication of performance, and certainly the technique reduces the difficulty of testing, multiple shots are desirable to build up confidence in the shot to shot consistency of the armour performance. This is particularly so with complex targets where significant variations in behaviour may occur depending on where the projectile impacts.

4. INTERPRETATION OF DATA IN TERMS OF RANGE

Presentation of ballistic data is enhanced if put in the form of a range at which a particular threat is defeated. This is possible using the data of Fig. 2 provided information is also available on the projectile velocity as a function of range. In the following discussion a procedure for transforming data in this way is described by carrying through the calculations for a particular sample problem. The principles of the method are introduced as the problem is worked.

For hard, pointed projectiles the mechanism of penetration into a semi-infinite target, and perforation through a finite target, is such that the depth or thickness (P) is approximately proportional to the kinetic energy or velocity squared (V^2) [5]

$$P = K V^2 \qquad (5)$$

where K is a constant dependent on the target material properties and the projectile mass and diameter. Thus any decrease in depth of penetration ΔP can be related to a drop in the square of the projectile impact velocity,

$$\Delta P = K \Delta V^2 \qquad (6)$$

There are three simple methods of determining the constant K which is required for the following analysis:

(a) If the following parameters are known, V_r, the velocity at which the projectile just defeats the vehicle side (50 mm thick in the present case), P_o, the depth of penetration into the witness pack at the muzzle velocity (850 ms^{-1}), as in Fig. 1, then K is given by $(P_o - 50)/(850^2 - V_r^2)$.

(b) If the depth of penetration into the witness pack (or the thickness of witness pack armour defeated) as a function of velocity is known, then a plot of $P_o - P$ versus $(V_o^2 - V^2)$ can be constructed and the slope of a line of best fit is the value of K.

(c) If only one point is known for a depth of penetration at a certain velocity, (eg P_o measured at the muzzle velocity, V_o, in Fig. 1), then assuming that at zero velocity there is zero penetration, K is given by $(P_o - 0)/(V_o^2 - 0)$.

Procedure (b) is the most accurate as the method outlined below is graphical so that it is possible to handle a non linear relationship. Method (a) has been found to be very accurate since it effectively uses two data points and the relationship is very close to linear in practice. Method (c) introduces a significant error such that the final results can be considered indicative and comparative. Figure 3 shows the reduction in depth (ΔP) as a function of reduction in velocity squared (ΔV^2) for the 12.7 mm AP projectile.

At this point, it is assumed that the reduced value of V^2 due to going through the add-on plate is equivalent to taking some kinetic energy from the projectile, and hence effectively reducing the muzzle velocity. This completely neglects the detailed mechanics of projectile break-up and the induction of instability and yaw, however it provides an effective means of obtaining a quantitative expression of the data in terms of range with the minimum experimental sample.

Figure 2 shows that in order to just prevent the projectile from defeating a vehicle side of thickness 50 mm a reduction in penetrating capability of 25 mm is necessary (i.e. ΔP = 75 mm - 50 mm = 25 mm). Figure 3 shows this to be achieved by reducing the velocity squared of the round by $\Delta V^2 = 240 \times 10^3\ m^2/s^2$ which, according to

$$V_p^2 = V_0^2 - \Delta V^2 \qquad (7)$$

represents an impact velocity on the vehicle side of $V_p = 695$ m/s. The velocity/range data for this round, presented in Fig. 4, shows this impact velocity would be achieved if the projectile were fired from a range of $X_r = 370$ m. The situation is shown in Fig. 5(a). This may be plotted as a point on the ordinate of Fig. 6 showing at zero weight of applique added, the vehicle is vulnerable at 370 m.

Now consider the point S in Fig. 2. The applique has reduced the residual penetration by 15 mm, and Fig. 3 shows this is equivalent to $\Delta V^2 = 145 \times 10^3$ m²/s². However this reduction is not sufficient to protect the vehicle side. It is therefore required that a distance X_1, be found such that the reduction in velocity due to the projectile travel from X_1 to X_0 added to the reduction caused by going through the applique leaves a residual velocity V_p which just fails to penetrate the vehicle side as depicted in Fig. 5(b). This can be done with the aid of the present analysis when we determine the projectile residual velocity after perforating the applique and establish the distance over which the projectile velocity decreases from this value to the critical value for penetration, V_p, Fig. 5(b).

In the particular case of point S, the result of reading Figs. 2 and 3 is that the residual velocity of the projectile after perforating the applique, V_1, (refer Fig.5 (b)) is given by

$$V_1^2 = V_0^2 - \Delta V^2 = (850^2 - 145 \times 10^3) \qquad (8)$$

giving $V_1 = 760$ m/s. Figure 4 indicates that the velocity of the projectile fired at a muzzle velocity of $V_0 = 850$ m/s will reduce to $V_1 = 760$ m/s after a flight distance of 200 m, and will further reduce to $V_p = 695$ m/s after 370 m. Thus a shot fired at the effective muzzle velocity of V_1 will decrease to V_p after travelling 170 m, Fig. 5(c). This then represents the distance X_1 from which the 50 mm vehicle side protected by the applique just defeats a 12.7 mm AP projectile fired at 850 m/s. Essentially the calculation procedure has treated the removal of projectile kinetic energy by the applique as equivalent to removal of the same amount of kinetic energy at the muzzle of the gun, or firing at the reduced muzzle velocity V_1 as in Fig. 5(c).

The procedure can be carried through for all the points of Fig. 2 and the oblique line and the Range versus Weight per Unit Area plot of Fig. 6 is obtained. Points below zero range represent no perforation of the up-armoured vehicle at point blank range. The weight of aluminium required to achieve the point blank protection is represented by the position at which the oblique line crosses the abscissa. The results of Fig. 6 are a clear indication of the trade-off between weight and ballistic protection. The relative effectiveness of various types of applique is easily gauged by representing all data points on one such graph. Whilst the method is generally applicable, a limitation is the case where severe shattering of the round leads to negligible residual penetration under all impact conditions. Such a case may arise from the impact of a tungsten carbide projectile on a hard applique. The method has been particularly useful with small calibre armour piercing projectiles where there is a strong dependence of projectile velocity on range. For large calibre rounds where the velocity drop with range is small it is expected that the errors in range estimation would be large.

The tedious nature of hand calculation and avoidance of errors is obviated by using a programmed procedure. Appendix I presents a listing of a simple program which allows direct conversion of data from Fig. 2 to Fig. 6.

5. CONCLUSION

Methods of ballistic assessment of armours have been examined, paying particular attention to techniques which increase efficiency of testing. A method has been developed whereby data on residual penetration into a reference target can be converted to the range at which a particular vehicle is defeated. This requires that the reference target configuration correspond to the vehicle side and that velocity/range data is available. The technique, which is particularly useful for the development of applique armours, is demonstrated using typical ballistic data and a nominal vehicle side thickness.

6. REFERENCES

1. Yaziv, I.D., Rosenberg, G. and Partom, Y., 9th International Symposium on Ballistics, RMCS, Shrivenham, Wiltshire, England, April 1986, 2-315.

2. Mascianica, F.S., in Ballistic Materials and Penetration Mechanics, Ed. R.C. Laible, Elsevier, Amsterdam, Oxford, NY, 1980, 41.

3. Ipson, T.W. and Recht, R.F., Exptl. Mechs. 15, 1975, 249.

4. "Military Specification Armor Plate, Wrought, High-Hardness" MIL-A-46100B, 29 July 1977.

5. Woodward, R.L., J. Australasian Inst. Metals, 22, 1977, 167.

APPENDIX I

RANGE' is an interactive program for carrying out the data reduction procedure described in the text. It is written in the Basic Language with prompts which ensure use is possible with minimal experience. The data of Figs. 2 and 4 can be used as typical input to obtain Fig. 6.

```
PRINT"**********************************************************************"
PRINT
PRINT"PROGRAM TO CALCULATE PROTECTION RANGE FOR VARIOUS THICKNESSES OF"
PRINT"           APPLIQUE OR ADD-ON ARMOURS."
PRINT
PRINT"**********************************************************************"
PRINT
PRINT
REM                        PROGRAM     RANGE
PRINT
PRINT"THIS PROGRAM REQUIRES ROUNDS TO HAVE BEEN FIRED INTO A WITNESS PACK"
PRINT"    BOTH WITH AND WITHOUT PROTECTION FROM AN APPLIQUE ARMOUR.      "
PRINT
PRINT"           HOWEVER,       AN APPROXIMATE"
PRINT"         PROTECTION RANGE FOR A PARTICULAR THICKNESS OF THE "
PRINT"         WITNESS PACK MATERIAL IN THE ABSENCE OF AN APPLIQUE"
PRINT"         CAN ALSO BE CALCULATED."
PRINT:PRINT

PRINT" DO YOU WISH TO USE IMPERIAL OR METRIC UNITS THROUGHOUT THIS PROGRAM"
IORM:PRINT:PRINT"                              I or M   ?"
REM                                                                   IORM
INPUT UNITS$
IF UNITS$="I" THEN GOSUB IMPERIAL
IF UNITS$="M" THEN GOSUB METRIC

IF UNITS$<>"I" AND UNITS$<>"M" THEN GOTO IORM

DIM T(100),W(100),RANGE(100),TOTALRANGE(100),X(100),Y(100),P(100),V(100)

PRINT:PRINT:PRINT
REM
REM
RESTART:
PRINT:PRINT:PRINT"   PLEASE TYPE IN A NAME FOR THE DATA FILE. ie 8STEEL.DAT"
INPUT RTFILE$
REM
REM
PRINT:PRINT:PRINT


PRINT
PRINT"                 THE VELOCITY-RANGE CURVE SHOULD BE AVAILABLE"
PRINT"                 FOR THE PROJECTILE USED FOR THESE SHOTS !"
PRINT:PRINT:PRINT


PRINT"        AN APPROXIMATE RELATIONSHIP BETWEEN PENETRATION DEPTH (P) "
PRINT"        INTO A WITNESS PACK AND KINETIC ENERGY (V^2) FOR THIS ROUND"
PRINT"                        WILL NOW BE DETERMINED"
PRINT:PRINT:PRINT

REM                                                              AGAIN1
AGAIN1:PRINT"         PLEASE SELECT THE APPROPRIATE METHOD ...."
PRINT:PRINT
```

```
PRINT"                          K ..  SLOPE KNOWN :  ie  P = K*V^2"
PRINT"                          S ..  SEVERAL P,V DATA PAIRS KNOWN"
PRINT"                          M ..  P KNOWN ONLY AT MUZZLE VEL."
PRINT:PRINT
INPUT PATH1$
IF PATH1$="K" THEN GOTO K
IF PATH1$="S" GOTO S
IF PATH1$<>"M" GOTO AGAIN1
GOTO M

REM                                                                  K
K:PRINT:PRINT:PRINT:PRINT
PRINT"     PLEASE TYPE IN A VALUE FOR  K  in  ";M$
INPUT KONST
PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
REM    CONTINUE ON TO  M  TO GET MUZZLE VEL. AND MAX. PENETRATION

REM                                                                  M
M:PRINT:PRINT:PRINT:PRINT:PRINT
PRINT"    A REFERENCE SHOT SHOULD FIRST BE FIRED POINT BLANK AT MUZZLE"
PRINT"           VELOCITY INTO A WITNESS PACK."
PRINT:PRINT:PRINT:PRINT
PRINT"ASSUMING THIS HAS BEEN DONE :"
PRINT"     WHAT IS THE MUZZLE VELOCITY FOR THIS ROUND ";C$
PRINT:PRINT
INPUT V0
V0=V0*XXX
PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT

PRINT"     WHAT WAS THE DEPTH OF PENETRATION INTO THE WITNESS PACK..."
PRINT"           (AT MUZZLE VELOCITY)..";A$

INPUT P0
P0=P0*WWW
PRINT:PRINT


PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT

REM   WORK OUT THE CONSTANT OF PROPORTIONALITY BETWEEN PENETRATION & K.E.
IF PATH1$="K" GOTO VEHICLE
KONST=P0/(V0^2)
GOTO VEHICLE

REM                                                                  S
S:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT

PRINT"  WHAT IS THE MUZZLE VELOCITY OF THE ROUND ?.. ";C$
INPUT V0
V0=V0*XXX
PRINT:PRINT:PRINT:PRINT
PRINT"   WHAT IS THE DEPTH OF PENETRATION INTO THE WITNESS PACK ..."
PRINT"           (AT MUZZLE VELOCITY).. ";A$
INPUT P0
P0=P0*WWW
```

```
PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
PRINT"        ALL THE DATA POINTS (INCLUDING THE MUZZLE VELOCITY DATA)"
PRINT"                WILL NOW BE TYPED INTO A DATA FILE ."
PRINT:PRINT:PRINT:PRINT:PRINT:PRINT

PRINT"PLEASE TYPE IN A NAME FOR PENETRATION,VELOCITY DATA FILE .."
PRINT:PRINT:PRINT
INPUT PVDATA$
PRINT:PRINT:PRINT
PRINT"    HOW MANY DATA POINTS ARE AVAILABLE  ..?"
PRINT:PRINT
INPUT NUMBER2
PRINT:PRINT:PRINT


PRINT"  TYPE IN THE DATA POINTS SEPARATED BY A COMMA  ie. P,V  "
FOR I = 1 TO NUMBER2
OPEN PVDATA$ FOR APPEND AS #2
PRINT"  DATA PAIR  ";I
INPUT P(I),V(I)
WRITE #2,P(I),V(I)
PRINT:PRINT
CLOSE .
NEXT I


REM   LEAST SQUARES FITTING ROUTINE FOR DETERMINING K:  P = K*V^2


X1=0:Y1=0:X2=0:X3=0
FOR I = 1 TO NUMBER2
X(I)=(V(I)^2)
Y(I)=P(I)
X1=X(I)+X1
X2=(X(I)^2)+X2
X3=X(I)*Y(I)+X3
Y1=Y(I)+Y1
NEXT I

N=NUMBER2
KONST=ABS((N*X3-X1*Y1)/(N*X2-((X1)^2)))
PRINT:PRINT:PRINT:PRINT

REM                                                                VEHICLE
VEHICLE:
PRINT KONST,P0,V0
PRINT "  WHAT IS THE THICKNESS OF THE VEHICLE ARMOR TO BE "
PRINT"        PROTECTED BY THE APPLIQUE";A$
INPUT P
P=P*WWW

PRINT:PRINT:PRINT:PRINT:PRINT
```

```
REM VEL IS THE IMPACT VELOCITY AT WHICH THE UNPROTECTED VEHICLE ARMOR
REM                  IS JUST SAFE FROM THIS ROUND       ie V50

REM                                                              EQUATION1
EQUATION1: VEL=(V0^2-(P0-P)/KONST)^0.5
VEL=VEL/XXX

PRINT"   THE VELOCITY AT WHICH THE UNPROTECTED VEHICLE ARMOUR IS JUST "
PRINT"          SAFE FROM THIS ROUND IS ..";VEL;"  ";K$


PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT

PRINT"    AT WHAT RANGE DOES THE PROJECTILE VELOCITY DECREASE FROM"
PRINT"          THE MUZZLE VELOCITY TO  ";VEL;K$;"  ?     in";D$
PRINT

INPUT TOTALRANGE(0)

PRINT:PRINT:PRINT:PRINT:PRINT

PRINT" THIS IS THE RANGE AT WHICH THE UNPROTECTED ARMOR"
PRINT"                          IS JUST SAFE FROM THIS ROUND."

OPEN RTFILE$ FOR APPEND AS #1
WRITE #1,TOTALRANGE(0),0
CLOSE

PRINT:PRINT

REM **************************************************************************

REM          ADDITIONAL APPLIQUE THICKNESSES

REM **************************************************************************
REM                                                              NEWAPPLIQUE
NEWAPPLIQUE:

PRINT:PRINT:PRINT:PRINT:PRINT

PRINT "    HOW MANY DIFFERENT THICKNESSES OF APPLIQUE WERE TESTED ?"
INPUT B
IF B=0 GOTO AGAIN
PRINT:PRINT
REM                                                                    Q1
Q1:PRINT"   DO YOU WISH TO ENTER THE APPLIQUE DATA IN TERMS OF  "
PRINT"                                   A      AREAL DENSITY      OR"
PRINT"                                   T      THICKNESS  ?"
PRINT:PRINT:PRINT:PRINT

INPUT Q1$
IF Q1$="A" THEN GOTO A1
IF Q1$<>"T" THEN GOTO Q1
M$="THICKNESS"
O$=J$
```

```
PRINT "        WHAT IS THE DENSITY OF THE APPLIQUE..";E$
INPUT D
RRR=D*UUU
GOTO A2

REM                                                                       A1
A1:M$="AREAL DENSITY"
O$=L$
RRR=1

REM                                                                       A2
A2:

FOR J=1 TO B

PRINT:PRINT:PRINT:PRINT:PRINT:PRINT

PRINT"WHAT IS THE ";M$;" OF THE APPLIQUE FOR SHOT ";J;" ? ";O$

PRINT
INPUT T(J)
REM WEIGHT PER UNIT AREA
W(J)=T(J)*RRR

REM W(kg/m^2 OR W(lbs/sq ft)

PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT

PRINT"      WHAT WAS THE DEPTH OF RESIDUAL PENETRATION INTO THE
PRINT"         WITNESS PACK PROTECTED BY THIS APPLIQUE THICKNESS..";A$
PRINT

INPUT PR
PR=PR*WWW


REM    CALCULATION OF EFFECTIVE RESIDUAL VELOCITY
REM            ASSUMING THAT DEFEATING THE APPLIQUE IS EQUIVALENT
REM            TO FIRING INTO THE PACK AT EITHER REDUCED VELOCITY
REM            OR FROM GREATER RANGE.


REM                                                                EQUATION2
EQUATION2:VELR=(V0^2-(P0-PR)/KONST)^0.5
VELR=VELR/XXX
PRINT:PRINT:PRINT

REM       NOW THAT THE RESIDUAL VELOCITY AFTER PENETRATING THIS APPLIQUE IS
REM             KNOWN WE CAN CALCULATE HOW MUCH FURTHER DOWN RANGE THE
REM             GUN IS REQUIRED TO BE PLACED IN ORDER TO JUST DEFEAT THE
REM             PROTECTED ARMOUR.


PRINT:PRINT
```

```
REM                                   WE KNOW BOTH VELR AND VEL NOW TO
REM                                   DETERMINE THE RANGE OVER WHICH THE
REM                                   ROUND WOULD DECREASE FROM VELR TO
REM                                   VEL
PRINT:PRINT

PRINT"     AT WHAT RANGE DOES THE VELOCITY DECREASE FROM THE MUZZLE"
PRINT"                 VELOCITY TO   ";VELR;K$;"   IN   ";D$;" ?"

INPUT TOTALRANGE(J)
RANGE(J)=TOTALRANGE(0)-TOTALRANGE(J)

PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
OPEN RTFILE$ FOR APPEND AS #1
WRITE #1,RANGE(J),W(J)
CLOSE

PRINT:PRINT:PRINT:PRINT:PRINT:PRINT

PRINT"         THE VEHICLE ARMOUR WILL BE SAFE FROM THIS ROUND"
PRINT
PRINT"      - WHEN PROTECTED BY AN APPLIQUE OF AREAL DENSITY   ";W(J);L$
PRINT:PRINT
PRINT"                             AT RANGES GREATER THAN  ";RANGE(J);D$

NEXT J

PRINT:PRINT:PRINT
AGAIN:
PRINT"                  DO YOU WISH TO RUN THIS PROGRAM AGAIN ?        Y    "
PRINT"                                   REVIEW THE DATA FILE ?        D   "
PRINT:PRINT:PRINT"                           OR EXIT THIS PROGRAM ?        X"
PRINT
INPUT PATH$
IF PATH$="Y" THEN GOTO RESTART
IF PATH$="D" THEN GOTO GETDATA
IF PATH$="X" THEN GOTO FIN
GOTO AGAIN

GETDATA: OPEN RTFILE$ FOR INPUT AS #1
PRINT F$,G$
FOR J = 1 TO B+1
INPUT #1,RANGE,AREALDENS
PRINT RANGE TAB(40) AREALDENS
PRINT
NEXT J
CLOSE
GOTO AGAIN

FIN:END


REM *************************************************************************
```

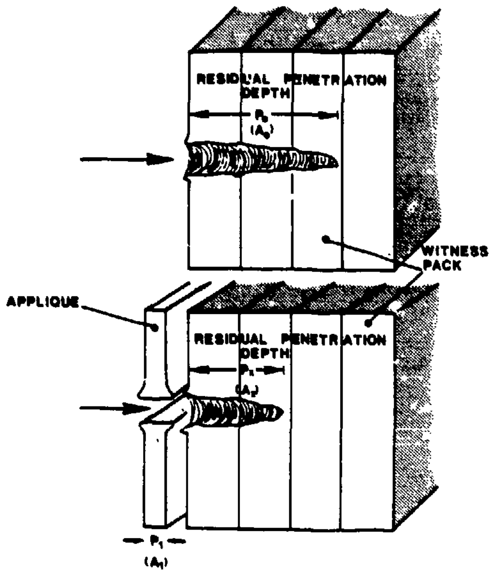

FIGURE 1 Ballistic testing using a thick reference pack to measure residual depth of penetration.

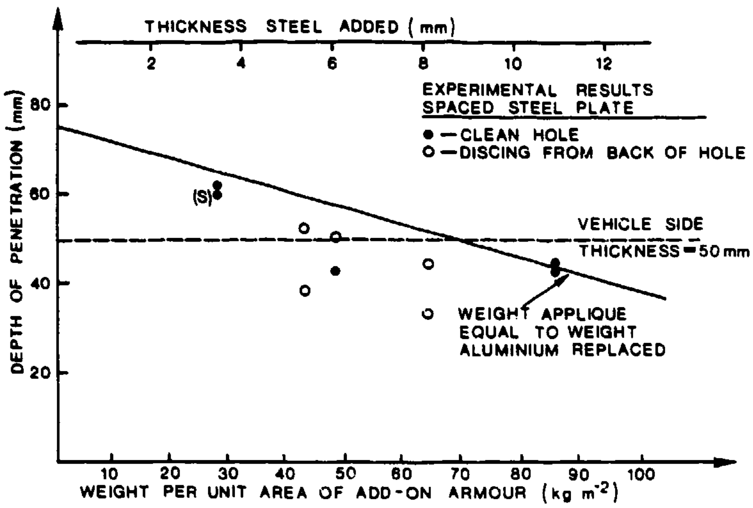

FIGURE 2 Residual depth of penetration into aluminium pack as a function of weight per unit area of add-on armour.

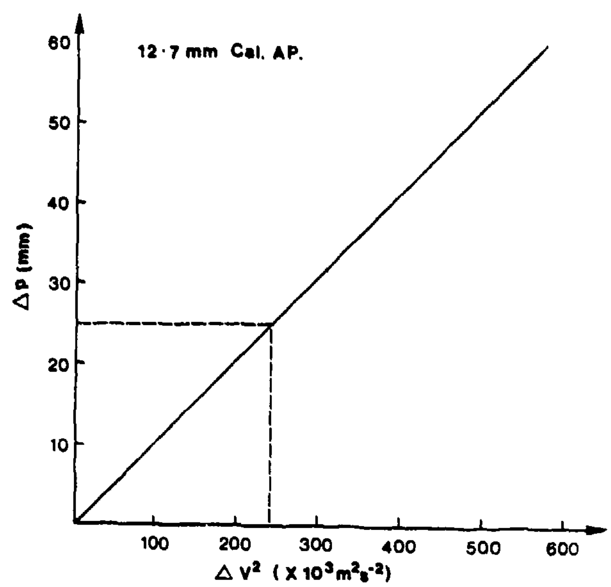

FIGURE 3 Reduction in penetration depth into the aluminium reference pack, ΔP as a function of reduction in kinetic energy represented by ΔV^2.

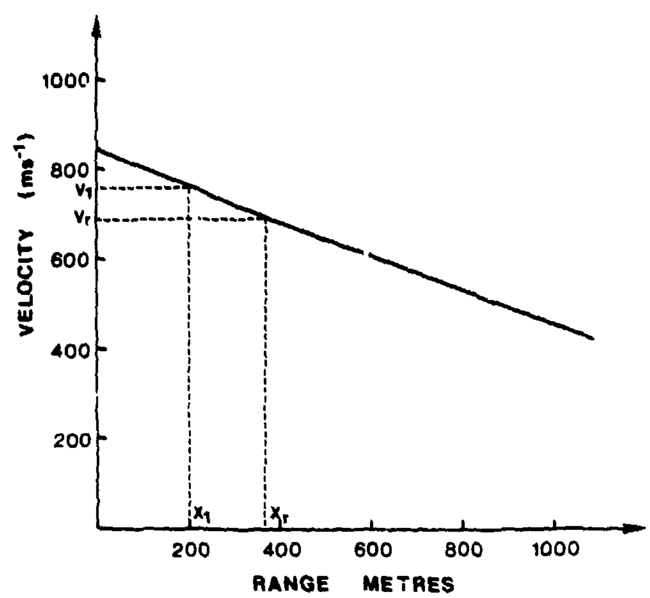

FIGURE 4 Velocity/range data for 12.7 mm AP projectile.

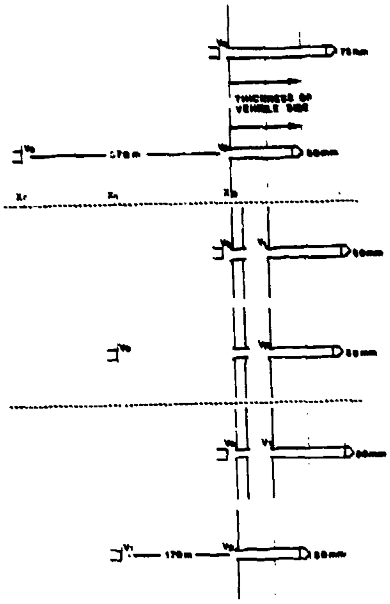

FIGURE 5 Evaluation of range at which armour defeats threat. Three configurations are shown as discussed in the text.

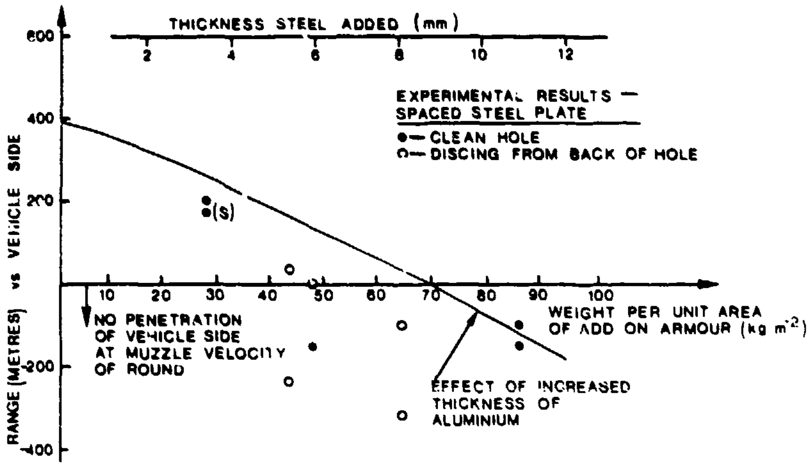

FIGURE 6 Plot of range at which vehicle side is matched by the 12.7 mm AP projectile as a function of weight of armour added.

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Ballistic evaluation of applique armours - presentation and interpretation of ballistic data

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ABSTRACT

Techniques of carrying out armour evaluations are reviewed. Attention is given to methods of comparison which use the residual penetration into a reference block, a method which is particularly useful with applique armours. It is shown how such data can be represented in terms of weight per unit area, and combined with velocity/range data to show the ranges at which armours are defeated as a function of weight.

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