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A4_13 Academic armour

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Abstract
This article considers the use of the first year physics textbook, *Physics For Scientists and Engineers* by Paul A. Tipler and Gene Mosca (hereafter referred to as "Tipler") as body armour. The scenario is imagined in which the book is struck by a bullet and it is considered as to whether the bullet would or would not penetrate through the book. It is found that the bullet would penetrate and hence the text would not be of much use as body armour.

Introduction

The first year of many physics university courses is taught with the aim of a single, all-encompassing textbook on the subject. As they are required to encompass a wide range of material, such introductory undergraduate level texts tend to be large and weighty and there is sometimes the joke made about them that they could "stop a bullet". Using the textbook for the first year physicists at the University of Leicester (*Physics For Scientists and Engineers*) by Paul A. Tipler and Gene Mosca) it shall be investigated whether a bullet is indeed capable of penetrating such a book.

Model

For the purposes of this investigation there are several assumptions that will be made. It shall be assumed that the bullet is being fired by a British Army standard issue SA80 assault rifle from close range (therefore ignoring air resistance). The rounds fired from the rifle shall be assumed to be cylindrical in shape, although they are obviously shaped to better penetrate any surface they should encounter. The book shall be assumed to be the sixth edition of Tipler and it will be assumed to be a paperback book, with all the pages, including the cover being the same composition. The energy of the bullet will be calculated and then the energy required to penetrate the book. Obviously, if the bullet has more energy than required to break through the book, then Tipler will be deemed unfit for use as armour.

Tipler will be considered paperback for the purposes of this investigation, with paper quality at the low end of that used for office purposes. These assumptions simplify the calculations slightly and won't affect the final result.

Paper has a rupture strength, which varies for different qualities of paper and represents how much pressure must be applied to a sheet of paper in order to pierce (or rupture) it. The higher the quality of the paper, then the higher this value will be. If one multiplies this by the cross-sectional area of the bullet that will be used, then one obtains the force that will be required to pierce a single sheet of paper. Eq. (1) is the familiar expression for the work done by a body, and Eq. (2) is the same expression, but for a constant force, with W the work done by the body, F the force exerted by the body and x the distance travelled.

$$W = \int_{x_1}^{x_2} F_x \mathrm{d}x. \tag{1}$$

$$W = F_x x. \tag{2}$$

Modelling the book thus as a single bulk piece of paper with a bursting strength equal to the the sum of the bursting strength of the individual, it should thus be possible to calculate the work done to penetrate the whole book and this can be called the energy of penetration (E_p).

The kinetic energy of the bullet can be found using the familiar expression seen in Eq. (3), with m the mass of the bullet and v its velocity, which shall be equal to the muzzle velocity of the rifle as we are assuming a frictionless environment.

$$KE = \frac{1}{2}mv^2. \tag{3}$$

If $E_p > KE$ then the book will have stopped the bullet and if not, then the bullet will have penetrated the book.

Object Properties

The SA80 rifle is a relatively low calibre weapon with a muzzle velocity of 940 ms^{-2} [1]. The bullets used have a mass of around 4 g (excluding the expended casing) and a radius of 5.7 mm [2]. Tipler consists in total of 800[1] sheets and with each of its sheets being considered office quality, this means that they have a bursting strength of about 250 kPa [3].

[1] For the sixth edition of the text.

Analysis

Using Eq. (3) along with the values given for the bullet and rifle in question, the kinetic energy of the bullet can be calculated as 3534 J. This means that $KE = 3534$ J.

The cross-sectional area of the bullet (assuming a cylindrical bullet) is 1.02×10^{-4} m^2. Knowing the bursting strength of the paper means that one can work out the force that would need to be applied by the bullet to break through a single sheet of paper. On would now calculate the work done to break through this single sheet and sum this value over all of the sheets of paper, but in practice it is easier (and mathematically identical) to add up the force to break through each piece of paper individually and then sum it over the thickness of the book. This means that the work done by the bullet to break through the book is given by Eq. (4),

$$E_p = BANx. \tag{4}$$

with B the bursting strength of a single sheet of paper, A the cross sectional area of the bullet, N the number of sheets in the book and x the thickness of the book. Using this expression together with the values previously mentioned and the measured thickness of Tipler (approximately 5.2 cm), one obtains that $E_p = 1061$ J.

Discussion

It can be seen from the above values that $KE < E_p$ and so the bullet would indeed penetrate Tipler. This does ignore the fact that the bullet is shaped, but this simply means that the bullet will pass through the book even more effectively, so is not really an issue.

Conclusion

It has been demonstrated that first year physics books should not be used as a replacement for professionally produced body armour as it is unable to prevent the penetration of a bullet fired from even a comparatively low calibre weapon despite the shaped nature of the bullet being ignored, which could be expected to significantly the penetrative properties of the round. It remains to be seen what would happen to the spinal structure of students who did indeed have a textbook that could stop a bullet.

REFERENCES

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[2] www.inetres.com/gp/military/infantry/rifle/556mm_ammo.html (26/02/2011)
[3] www.paperonweb.com/paperpro.htm# Strength Properties (26/02/2011)