Bullet in the Block Mystery

This worksheet will be completed in recitation after watching a short video at the beginning of class. The paragraphs below summarize the information presented in the video.

If a vertically mounted .22 gauge rifle fires a bullet upwards into a block of wood in line with the block's center-of-mass, the bullet penetrates into the block causing it to rise almost one meter without spinning as was demonstrated in the video vignette. If the shot is repeated with the bullet hitting a block "off center" (Figs. 1b and 2b), would the block travel straight up or in another direction? Would it be spinning? Would it rise to the same height?

Fig.1: A rifle aimed at a 2"x4" block edges: [a] on center and [b] off center.

It turns out that the "off-center" bullet causes an identical block to rise straight up *to what appears to be the same height*, except that the block acquires rotational kinetic energy and spins counter-clockwise as it rises and falls. This is puzzling. How can the bullet impart more kinetic energy to a block that's shot "off-center" and yet the blocks *rise to the about the same height*? This doesn't seem to make sense.

Maybe the off-center bullet doesn't penetrate as far into the block, so that more of its initial energy is available to start the block spinning. However, x-rays of two blocks depicted in Fig. 5 do not appear to show any measurable differences in penetration depth of the bullets.

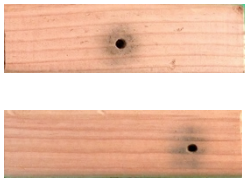


Fig. 2: Edges of 5" lengths of 2x4 hit (top) on-center and (bottom) off center.

This is a mystery. Are the laws of physics being defied? Perhaps the energy lost as a bullet penetrates into a block is much greater than the kinetic energy it imparts to the block. Then a small, immeasurable change in penetration distance could result in significant changes in a block's linear and rotational kinetic energy.

If the energy a bullet loses changing its shape and breaking chemical bonds in the wood is much larger than the linear and rotational kinetic energy acquired by the block, then the height difference between a spinning and non-spinning block might not be measureable.

In this tutorial, you can use the data from a manufacturer the mass and muzzle velocity of a .22 gauge bullet to investigate possible explanations for this strange occurrence.

Data and other necessary information:

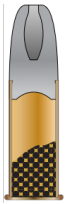


Fig. 3: A hollow point bullet and its casing containing air and gunpowder

Bullet info: The .22 gauge bullets used in the videos you are analyzing were manufactured by CCI.

Bullet Mass (w/o casing): $m_b = 2.3$ g $= 2.3\text{x}10^{-3}$ Kg

Muzzle Speed of the Bullet: $v_b = 384$ m/s. Note that this is probably an average or a maximum. There will obviously be differences from bullet to bullet because the amount of gunpowder in the casing that ignites to push the bullet upward may vary.

Fig. 3: A 2" x 4" block is suspended by nails between two pieces of Plexiglas so that it is free to move upward when hit from below by a bullet.

Block info: The blocks used in this bullet-block experiment each had a mass, M, of about 0.222 kg and a face length and width given by $L = 0.127$ m and $W = 0.102$ m.

Mass of nail 3.8g $=3.8\text{x}10^{-3}$kg

Rotational Speed of a Typical Spinning Block: $\omega = 73$ *rad/s.*
(To determine rotational speed, ω in radians per second of a typical rotating block, we acquired typical spin rate data by viewing the video. One segment recorded at 2 min 52 sec shows a 500 fps B&W image of the spinning block that took 43 frames to complete a full turn. So the time for a single turn through an angle of 2π radians was given by $T = (43/500)$s = 0.086s per turn.)

Maximum Height reached by blocks: .83m

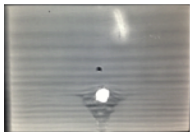
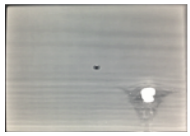
(a)  (b) 

Fig. 5: X-ray images of 5" lengths of 2" by 4" pine board showing the bullet penetration into each block: (a) on-center (left image) or (b) off- center (right image). The small holes halfway up each block are the support nails mounted at the center of each block's face.

Bullet Penetration: Identical blocks of length 12.7cm The x-rays in Figure 5 shows what happens to the bullet when a block is shot (a) on-center and (b) 3.4cm right of center.

The equation needed to calculate the rotational kinetic energy of rectangular block spinning about its center of mass is

$$K_r = \frac{1}{2} I \omega^2$$

I is the block's rotational inertia and ω denotes the magnitude of its angular velocity (rotational speed in our case).

The equation for rotational inertia, I, derived in most introductory textbooks for a flat block of length L and width W spinning around its center of mass is given by

$$I = \frac{1}{12} M(L^2 + W^2)$$

Name_____ Section_____

Tutorial: Bullet in a Block

This is a special follow up to the work you started with the online vignette. You should work with your group throughout this assignment.

$m\boldsymbol{v} = \boldsymbol{p} \equiv$ momentum $\Delta\boldsymbol{p} \equiv$ Impulse In an isolated system $\Delta\boldsymbol{p} = 0$ or … $\boldsymbol{p}_{before} = \boldsymbol{p}_{after}$ $\mathrm{I} = \frac{1}{12}M(L^2 + W^2)$	$\frac{1}{2}I\omega^2 = K_r \equiv Rotational\ Kinetic\ Energy$ $\frac{1}{2}mv^2 = K \equiv Kinetic\ Energy$ $mgh = U_g \equiv Gravitation\ Potential\ Energy$ Use g= 9.8 m/s² where needed.

I. Hypotheses

You may or may not have some definite thoughts on how to explain the Bullet and Block phenomenon you observed. Suppose a table of students has seen the original part of the video, but not an explanation.

They offer the following ideas:

Albert: In an off-center shot some of the U_g goes into K_r. However, the K_r is insignificant compared to the U_g so the height difference is not measurable.

Enrico: The spinning block might have been just a little less in mass or the bullet might have had a slightly higher velocity … canceling out loss to K_r.

Ernest: The spinning block acts like a windmill decreasing the air resistance. Hence … the block can go as high as before even though it cannot gain as much U_g. Less air resistance force means it will be able to 'make up the height difference'.

Niels: An off-center shot doesn't go into the wood as far. This "extra" energy to go toward K_r.

Richard: U_g & K_r are much smaller than K_{before} (i.e. most of the K went into deforming and heating the wood.) <u>There is a difference</u> in height, but it is difficult to measure since U_g & K_r are such a small portion of the original K.

Elmo: In an inelastic collision the linear momentum is conserved, but the kinetic energy is not.

How can we go about determining who has the right idea? (rhetorical)

II. Investigating Ideas

Your group will examine the 'merits' of each of these ideas. Your group's task is to investigate each and see if you can come to some understanding of the overall Bullet and Block Mystery.

A. Cutting down the list:

Suppose Bert, the TA, walks by the students. He notes two of the ideas being proposed, while interesting, would require further data collection to either support or not support each idea.

1. Which ideas is Bert referring to and what additional data is needed?
2. Pick one of ideas from #1: What would you do with the new data?
3. For this same idea: How would you know if the data supported the hypothesis?

✯ *Consult an instructor before you proceed.*

B. Discuss as a group the remaining ideas and choose one to investigate.

1. Which physics principle(s) is/are involved in the idea your group chose to investigate?
2. What data will be needed to do a calculation?
3. How will you know if the calculated number supports or does not support the hypothesis?
4. When using 'real-world data' you may find the numbers you calculate are not exactly equal. How close is 'close enough'? What % error is reasonable? Provide a reason along with a number.
5. Go thru and do the calculations. What conclusion do you draw for this hypothesis?

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C. Whether the hypothesis you investigated is supported or not, it is important to explore the other options as well. It is possible that the best model contains ideas from more than one hypothesis.

Choose another of the hypotheses and repeat the process of investigating to determine if the idea has support. Follow the same investigation procedure as outlined in part B. You will work thru as many of the hypotheses as possible until the TA does a wrap-up at the end of the class.

D. Devise and describe a 'next step' experiment that could be used to further investigate this phenomenon. Use the first three questions in letter B as a guide for what to include in your response.

✯ *Consult an instructor before you proceed.*