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Car hits boy on bicycle

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Abstract

In this article we present the fascinating reconstruction of an accident where a car hit a boy riding his bicycle. The boy dramatically flew several metres through the air after the collision and was injured, but made a swift and complete recovery from the accident with no long-term after-effects. Students are challenged to determine the speed of the car from the accident data. Relevant features for discussion include kinematics, conservation of momentum, energy, assessing the elasticity of the collision, the medical report, and knowledge of the scene of the accident through a photograph and an aerial perspective.

Background

Students engage in rich learning and build coherent conceptual frameworks when they are given opportunities to apply their knowledge to meaningful problems [1]. The reconstruction of traffic accidents, used by teachers for decades [2], is an excellent real-life application of the powerful laws of physics, and a challenge to which introductory students respond enthusiastically.

Our accident occurred 4:30 pm on a day in September 1961 in the once very beautiful Yorkship Village (now called Fairview) at the southern tip of Camden[1], New Jersey. Yorkship Village, built in 1918 for shipyard workers after the British concept [4] of the 'garden city,' is a historic 225 acre (90 ha) village representing one of the best achievements in progressive housing of the early 20th century [5,6]. Figure 1 shows the street where the accident took place, photographed from Yorkship Square, the focal point of the village.

Figure 2 presents the aerial view, where a seven-year-old boy named Ken[2] carelessly sped out of an alley (vertical arrow in figure 2) on his 20" bicycle (51 cm diameter wheel). This impulsive behaviour occurred after Ken got annoyed with his older brother Den (and bicycle riding partner) behind Lenny's Realty (see the building to the right of the bicycle path). The bicycle darted in front of an approaching 1961 Rambler[3], which had just turned from Yorkship Square onto America Road.

Den[4] saw the collision that knocked Ken off the bicycle and sent him ten metres down America Road in the direction the car was heading. The car then proceeded to run over the bike. The instant before impact, Ken had instinctively raised his right leg parallel to the

[1] In 2004, Camden was ranked by Morgan Quinto Press as the most crime-ridden city in the United States [3].

[2] Kenneth L Ruiz (b. 1954), the author's brother.

[3] The driver was a middle-aged woman with her husband in the passenger seat.

[4] Dennis R Ruiz (1952-2002), also the author's brother. For decades, Dennis remained adamant that Kenneth was thrown 10 metres, which includes the vault distance (airborne) and sliding-tumbling distance.

Figure 1. Viewing the street of the accident from Yorkship Square. Photo by the author (2001).

road to avoid being crushed (raising his centre of mass somewhat). After flying through the air, he fractured his lower back skull and he was found lying unconscious in the street with his head on the kerb. He landed at the edge of the road since the bike's initial velocity was perpendicular to the car's direction. There were no other injuries, no scrapes and no ripped clothing.

Teachers may digress here and take this as an opportunity to point out the importance of wearing safety helmets. Bicycle helmets were not commonly used in the United States over a generation ago in the early 1960s. Students can also be warned not to operate any kind of vehicle when they are angry.

Ken shortly came to, wondering what he was doing so far down the street. He was not able to walk without support as his legs kept giving out. Mr. Lenny, having heard the accident from the realty building, rushed Ken to West Jersey Hospital. Ken spent one week with a swollen head and a severe headache. He fully recovered after resting two additional weeks at home. The questions for our students are those of great interest to insurance companies and lawyers. What was the speed of the oncoming car on impact? Was the driver maintaining a safe speed for this residential neighbourhood? Could she have stopped?

Such questions can be assigned to groups of students. Typically there is not one precise answer to a complicated real-life problem and experts often debate such questions in court, although our accident was settled peacefully out of court. One complication is that the total distance traveled by a pedestrian or cyclist

Figure 2. Aerial view of where the car hit the bicycle. Aerial image Courtesy GlobeXplorer.

after a collision (called the throw distance in the literature) is composed of the airborne distance (the trajectory range or vault distance) and a subsequent combination of bouncing, tumbling and sliding (referred to as the sliding distance) [7]. We will consider two approaches to our reconstruction of the accident below.

Simplified analysis

Our problem is easier if we know where the boy first hit the ground (the vault distance). In our simplified analysis, we take the vault distance to be 5 m, half of the observed 10 m throw distance. This is simply an approximate guess. Note that our throw distance and vault distance are for the component of the displacement along the direction of the street, the direction in which the car was heading during the accident. The displacement of the cyclist along his original direction of travel is due to the initial speed of the bicycle moving across the street, which is perpendicular to the street direction, and thus not relevant for the collision equations we will see below.

Our problem is rich enough for the introductory student if the student begins with the vault distance as a rough guess or as given information for the problem. However, our second approach will be more challenging. In real life, one usually knows with confidence the throw distance rather than the vault distance because the former is marked by where the pedestrian or cyclist finally comes to rest. Our second analysis will illustrate the power of physics as we work from the throw distance, using a model for the tumbling portion of the path.

Conservation of linear momentum in the direction the traveling car was traveling gives

$$MU = MV + mv$$

where M is the mass of the car, m is the mass of the boy, U is the initial speed of the car, V is the final speed of the car and v is the final speed of the boy in the direction of the car's motion. We work with the dimension parallel to the direction of the car's motion.This is justified since the collision took place along this direction and the observed throw distance was for the boy's displacement along this same direction. The perpendicular component of the boy's velocity afterwards (relative to the throw direction) was equal to the initial bicycle velocity that was transporting the boy across the street.

We neglect the bicycle as we maintain that the car hit the boy's body and immediately afterwards ran over the bike. We are justified in this approximation as the change in momentum of the bike after the collision was essentially zero, based on our eyewitness. The boy flew through the air on impact, leaving the bicycle where it was.

Modelling the collision by Newton's Law of Restitution, we have the relation that the relative velocities of separation are a constant multiple, e (the coefficient of restitution), of their relative velocity of approach [8]. In mathematical terms, we have

$$v - V = eU.$$

Using conservation of momentum to eliminate the final speed of the car (V) we arrive at the following formula

$$U = \frac{M+m}{M(1+e)}v,$$

which is not too sensitive to different values of e near 1.

Since many introductory courses do not spend time deriving Newton's restitution relation, we take another approach. We consider the collision as approximately elastic since the medical report indicated no injuries other than the head injury, which occurred after the collision. In contrast, for an inelastic collision, kinetic energy is converted into internal energy of the colliding masses, which can deform them permanently. We consider our collision as having a 'good bounce' since neither the boy nor the car suffered deformation after impact. This approximation, which essentially takes the coefficient of restitution to be close to 1, eliminates the need to introduce the coefficient of restitution into our analysis.

Instead, we can write down the usual formula for the conservation of kinetic energy familiar to introductory students,

$$\frac{1}{2}MU^2 = \frac{1}{2}MV^2 + \frac{1}{2}mv^2.$$

We then use the momentum and energy equations to eliminate V. We proceed to express the initial speed of the car U in terms of v, obtaining

$$U = \frac{M+m}{2M}v,$$

which is the typical result for an elastic two-body collision in one dimension. Note that this result can be obtained from the restitution equation when $e = 1$.

Some students may consult references to estimate the mass of a 7-year-old and a 1961 Rambler, and later discover that these details offer only a small correction. Since $m << M$, the car's initial speed reduces to

$$U = \frac{v}{2}.$$

We find v by estimating the vertical distance h that Ken's center of mass must have fallen during the trajectory. The relevant kinematical equations are

$$h = \tfrac{1}{2}gt^2 \text{ and } d = vt,$$

where t is the time to reach the ground, d is the horizontal distance (airborne range), and $g = 9.81$ m s^{-2}. Combining these, we find

$$v = \sqrt{\frac{gd^2}{2h}}$$

and therefore, the speed of the car,

$$U = \frac{1}{2}v = \frac{1}{2}\sqrt{\frac{gd^2}{2h}}.$$

Roughly approximating the vertical fall as h = 1 metre (centre of mass of boy on bike to center of mass of boy on street) and using d

= 5 m for the airborne horizontal range, we find

$$U = \frac{1}{2}\sqrt{\frac{gd^2}{2h}} = \frac{1}{2}\sqrt{\frac{(9.81)(5)^2}{2(1)}}$$
$$= 5.54 \text{ m s}^{-1} = 20 \text{ km h}^{-1},$$

which is about 12 mph.

At some appropriate point, we can challenge students to become physics experts and arrive at this result mentally! We first note that when a large mass collides elastically with a smaller one at rest, the small one takes off at twice the speed of the larger mass. Think of bouncing a ball off a hard wall (no gravity). The ball bounces right back with the same speed. Now consider a reference frame where the ball is at rest and the wall moves toward the ball at speed U. Making a simple Galilean transformation, we see that the ball must leave with $2U$.

The next step in our quick mental calculation is to approximate the drop distance. We estimate that it takes about half a second to fall one metre, which can be verified by a timer or a wrist watch with chronograph. Therefore, the boy's horizontal speed must be v = 5 m/0.5 s = 10 m s^{-1} in order to travel the horizontal distance of 5 m within the same time frame. This readily gives an approximate speed for the oncoming car as $U = v/2$ = 5 m s^{-1}.

Further consideration includes the initial forward independent motion of the bicycle (in the perpendicular direction relative to the impact). This component of the boy's speed continued after the collision. It enabled Ken to reach the kerb of the road, where the concussion may have occurred.

Advanced analysis

In our second analysis we work with the throw distance, the distance we obtain from the scene of the accident. This more advanced approach can serve as a guided activity or as a follow-up discussion to prior student group work. Figure 3 depicts the trajectory of the cyclist from right to left in order to be consistent with the direction of the accident as seen in figure 2.

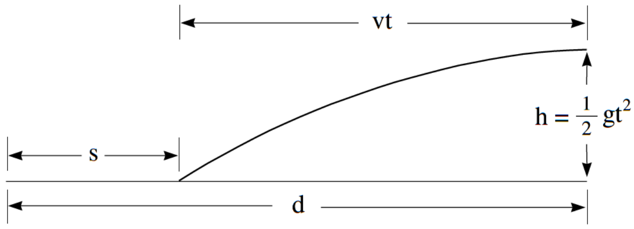

Figure 3. Throw distance d as the sum of vault distance vt and sliding distance s.

Figure 3 indicates the throw distance d as the sum of the vault distance (vt) and sliding distance (s). Then,

$$d = vt + s \text{ and } v^2 = 2\mu g s,$$

where μ is the coefficient of friction between the sliding mass and the road surface. The second equation comes from the kinematic equation ${v_f}^2 - {v_i}^2 = 2as$, where $v_f = 0$, $v_i = v$ and $a = -\mu g$ since the magnitude of the frictional force is $f = -\mu mg = ma$. When we substitute $t = \sqrt{\frac{2h}{g}}$ and $s = \frac{v^2}{2\mu g}$ in $d = vt + s$, we arrive at the following quadratic equation:

$$\frac{v^2}{2\mu g} + v\sqrt{\frac{2h}{g}} - d = 0.$$

Since Ken suffered no scrapes or torn clothing, we assume that he tumbled rather than slid. The literature gives 'effective coefficients' of friction μ where a tumbling pedestrian or cyclist is modelled in terms of an equivalent sliding mass. The range [7] is from 0.7 to 1.22. Note that values can exceed 1 for the 'effective coefficient of friction' since the contact forces between the cyclist and the street reach values considerably greater than the weight of the cyclist for some time intervals.

Here is one opportunity for students to appreciate that scientists often need to rely on published research data. For example, in addition to useful published values for the effective coefficient of friction, the literature [7] indicates that wind drag can be ignored for pedestrian launch speeds less than 40 km h^{-1}. For our calculation, we will take $\mu = 1$, along with $h = 1$ m, $d = 10$ m, and $g = 9.81$ m s^{-2}. We obtain

$$0.051v^2 + 0.452v - 10.0 = 0.$$

The positive solution from the quadratic formula gives v = 10 m s^{-1}, which implies a car speed $U = v/2 = 5.0$ m s^{-1} = 18 km h^{-1} = 11 mph.

Conclusion

We have performed an accident reconstruction of a real-life situation. We included details of the town and surroundings to help drive home the fact that this example is not contrived. We employed two approaches for our analysis. In the first case, we assumed the cyclist hit the ground roughly at the midpoint of his throw distance from the car, tumbling the rest of the way. In this way, the simplest basic laws of physics can be used with minimal calculations.

Next we showed how the power of physics allows us to work with the throw distance, the distance measured from the impact point to where the boy landed. This analysis again uses introductory physics formulas, but includes a little more mathematics, leading up to a quadratic equation. This method is known as the Collins model in accident reconstruction literature [7]. Our students can take pride in the fact that they actually get to derive the Collins formula in our second analysis and then apply it to the specific accident data available.

Students should be encouraged to vary input parameters in order to see how sensitive the outome is to the changes. What happens if we use $h = 0.8$ m for the falling distance of the centre of mass? Can we make a model to estimate the centre of mass of the boy on the bike right before the collision given the fact that one leg was parallel to the street? Can we give a lower and upper bound for the initial speed [5] of the car? What about the shadows in the aerial photograph obscuring the side of the road near the alley? Could they limit the ability of the driver to see the boy? What are the shadows at 4:30 pm in September? One needs to consult maps to ascertain which direction is north. How long does it take a bike to travel across the street [6]? What is a reasonable driver reaction time[7]? Finally, students can investigate the effect of taking the coefficient of restitution between the car and cyclist to be less than 1.

Many teachers [9] often give students answers rather than raise questions. However, a natural critical learning environment engages students in 'some higher-order intellectual activity: encouraging them to compare, apply, evaluate, analyze, and synthesize, but never only to listen and remember.' Our accident reconstruction presents an excellent way to achieve these goals.

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[5] My mother Agnes Ruiz and her neighbor Barbara Coscarello, both Fairview residents at the time of the writing of this article, drove the turn at the scene of the accident several times. In their opinion, the most probable speed just after making this turn is between 10 and 15 mph.

[6] Ken later explained that he accelerated as fast as he could behind the realty building, then coasted into the street.

[7] An eyewitness indicated that it was not possible for the driver to stop in this case. She said "I saw the whole thing. I was sitting on my porch. He rode his bike right in front of the car."

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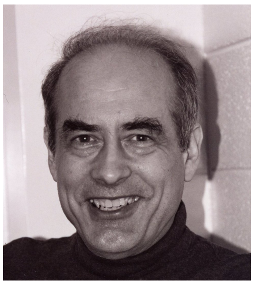

Ken L Ruiz, the author's brother, is the accident victim and subject of this article. Ken recovered completely from his accident within one month, and has graciously supplied the data and checked this article for its historical accuracy. Ken is now employed by the US Post Office and lives with his family in California.

Author's Note: Any original hyperlinks from the 2005 version of the publication that no longer work have been either updated or removed.