Serrata Ballistic Car - Cat. No. 1055002

Introduction:

The **Ballistics Car** is a device that demonstrates that **horizontal** motion of an object (in this case, a ball) is unaffected by **vertical** motion. It consists of a gun mounted vertically on a car which propels a steel ball upward by means of a compressed spring.

The car's low-friction wheel bearings allow it to **free wheel** at a speed that is essentially constant. If the gun is triggered while the car is free-wheeling, the ball rises and falls back into the barrel.

Compare this to actions within a moving train. Picture a passenger (the gun) inside a train (the car) throwing a ball straight up. The ball falls straight back into the passenger's hand provided the train moves at a constant speed. The Ballistics Car allows these proceedings to be watched by a stationary observer.

The purpose of the Ballistics Car is to show that the **horizontal component** of the ball's velocity must equal that of the car itself despite the considerable change in the **vertical component** of velocity.

This is the only way that the ball will fall back into the barrel of the gun, given any initial speed of the car and any initial power setting of the gun. This proves that velocity as a vector can be resolved into two mutually perpendicular components which can then be treated separately.

At any point in a projectile's trajectory, its instantaneous velocity can be resolved in two perpendicular directions. The directions commonly used are the horizontal and the vertical. Since the horizontal component stays constant while the vertical component changes due to the Earth's gravitational pull, the projectile's trajectory can be calculated and predicted. At higher speeds - speeds that cannot be attained by the Ballistics Car - the effect of air friction needs to be included since friction reduces both components of high velocity.

The Ballistics Car serves as an introduction to frames of reference which are moving at constant velocities relative to each other. The passenger in the train and the barrel of the gun are unaware of their respective movements. They *see* the ball move only in a vertical direction relative to their frame of reference. An observer on the ground, however. see the ball curve in a parabola relative to his frame of reference. The motion of the ball obeys Newton's Laws of Motion due to the effect of gravity in both frames of reference. An observer cannot tell from the motion of the ball whether he is moving at any constant horizontal velocity relative to the Earth.

Operation:

1. You need a level surface.

For this demonstration to work, you must run the car on a smooth, hard surface that is dust free and horizontal. Use a carpenters' spirit-level to make sure your surface is level. Even floors that look horizontal to the eye can been too inaccurate for the demonstration to work.

Check in directions both perpendicular and parallel to that of the car's motion.

Do not drop or allow the car to run off the edge of any table because the bearings can be damaged.

2. Position and shoot ball from barrel.

Place ball on piston inside the barrel.

Push down and insert the locking pin through either of the two holes in the side of the barrel so that it enters the groove in the side of the piston. This is *cocking* the gun.

Important: ***Insert the pin as little as possible. The further it is in, the more friction slows your car!***

Grasp the cord to the locking pin in one hand. With the same hand, **push** the car away from you. Once the car has left your hand, **jerk the locking pin out** with a sharp snap of the cord.

Too gentle a pull will slow the car too much.

The ball will rise about one foot for the lower locking pinhole and fall back into the barrel.

3. Try different speeds and both pin holes.

4. Provided conditions are right, the ball falls back into the barrel.

This confirms that the horizontal motion of the ball keeps pace with that of the car. For each locking position, the ball always rises to the same height regardless of horizontal velocity, again demonstrating the independence of the two perpendicular components.

A sceptic may claim that the car slows down awhile the gun is firing because of the pull on the pin, thus invalidating the demonstration. The car does indeed slow down, but, provided the pull is directly in the line of travel and that no rocking of the car occurs, the change in speed is complete before the ball has begun its free assent. The sceptic may be, convinced of this by a reversal of the motion. Pull the car toward you with a gentle pull on the cord and then give the sharp snap to pull the pin out. The same result occurs even though the car has increased its velocity.

Another cause for scepticisms is the obvious presence of some friction to slow the car down. Because the car velocity is not perfectly constant, the ball will fall slightly ahead of the centre of the barrel. With the air of some helpers and a simple stopwatch, you can quantify the effect in terms of how far ahead of the barrel centre the ball is expected to fall. This can be compared with the observed point of entry in the mouth of the barrel.

Measurements needed to Quantify how far ahead of the barrel the ball should fall.

1. **Height H** to which ball rises from the mouth of the gun.
   H can be measured with the car stationary.
2. **Distance D the car travels** from point where gun is tired to point where car, of its own accord, comes to rest.
3. **Time T taken for the car to travel until it comes to rest.**
   T and **D** must be measured together in the same trial.

Calculations - Part A:

Measurement of **H** allows you to calculate the time the projectile is in the air. To determine the relationship between distance **H** fallen to elapsed time **T** for an object starting from rest and undergoing a constant gravitational acceleration **g** (which equals 9.8m/s^2), use this equation:

$$H = \tfrac{1}{2} g T^2$$

The time from the top of the ball's flight to the barrel is:

$$T = \left(\frac{2H}{g}\right)^{1/2}$$

The lime taken to reach this height in the first place would have been the same. Thus the time of flight must be:

$$T = 2\left(\frac{2H}{g}\right)^{1/2}$$

Calculations - Part B:

The horizontal distance travelled by an ideal frictionless car would be given by the product of initial velocity, $\mathbf{V_0}$ and time. For a real car, you need to know how the velocity decreases with time due to friction. Since the friction is likely to be a constant force, you can assume the **V** decreases at a uniform rate. The acceleration is a *negative* constant, **a**. Thus the velocity will have dropped to 0. This is written as:

$$0 = V_0 + aT \qquad \textbf{Eqn 1}$$

Therefore:

$$D = V_0T + 1/2\, aT^2 \qquad \textbf{Eqn 2}$$

where **a** has a negative value.
From **Eqn 1**, derive:

$$V_0 = -aT$$

Substituting **Eqn 1** into **Eqn 2** gives:

$$D = -aT^2 + 1/2\, aT^2 = -1/2\, aT^2$$

Therefore:

$$a = \frac{-2D}{T^2}$$

The measurements of **D** and **T** are combined to give the (negative) acceleration of the car. This can now be used to calculate what happens during the flight of the ball.

While the ball is in the air for **T** seconds, the ball travels a horizontal distance $\mathbf{V_0T}$. The car however travels a dis-tance calculated as follows:

$$D = V_0T + 1/2\, aT^2$$

The ball travels further than the car. The further amount it travels is:

$$\Delta = V_0T - (V_0T + l/2A\, T^2) = -1/2\, aT^2$$

Substituting for **a** and **T** gives:

$$\Delta = -1/2\left(\frac{-2D}{T^2}\right)4\left(\frac{2H}{g}\right) = \frac{8DH}{T^2 g}$$

Typical values of:

D = 2.0 m
H = 0.27m
T = 12 sec

yields:

$$= \frac{8x2.0x0.27}{12^2\,x0.98} = 0.003\,m = 3\,mm$$

Therefore as long as the friction is low enough to give similar values of Δ (which are small compared with the barrel mouth), the demonstration is valid.

The **Ballistics Car** is a real world case which shows how the horizontal motion of an object is unaffected by vertical motion.

How to Teach with Ballistics Car

Concepts Taught:

Scalar vs vector quantities; velocity as a vector; horizontal and vertical components; their mutual independence. Projectile motion; Newton's Laws of Motion; Equations of Motion and calculation of variables using them; acceleration due to gravity.