



Forensic Reconstruction of an Anomalous Airborne Vehicle Trajectory Following Bridge Impact: A Physics-Based Case Study Using Projectile Motion Analysis

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Abstract

Reconstruction of Forensic Road Traffic Accidents (RTA) often relies on physical evidence such as tyre marks, skid marks, deformation patterns on vehicle, electronic vehicle data, and witness statements. In some rare road accident investigations, however, conventional indicators of vehicle speed are insufficient and making reliable accident reconstruction challenging. Under such circumstances, the application of classical mechanics provides a scientific theory for determining the motion vehicle. The present study describes and analyzes an unusual accident of SUV car that became airborne after impact with a roadside small bridge structure. The main aim of this study is to reconstruct the accident sequence and to estimate the approximate vehicle speed based on physical evidence, damages found on vehicle, trajectory characteristics, and projectile motion principles. The detailed analysis of the airborne trajectory of the vehicle in crime scene demonstrated that the vehicle travelled approximately 17.68 m through the air after impact with a road side bridge structure and before ground contact. Based on the equation of motion-free-fall equations and analysis of the horizontal projectile motion of the vehicle, the post-impact speed was estimated to lie within a plausible range of 120-130 km/h. This estimation demonstrates the principle of physics in RTA and describes airborne trajectory applications can provide scientifically defensible opinions in the absence of traditional speed indicators.

Keywords: Forensic Physics; Accident Reconstruction; Projectile Motion; Airborne Vehicle; Vehicle Dynamics; Speed Estimation; Forensic Engineering

Confidentiality Statement: Certain RTA measurements, dates, vehicle information, place of offence and investigation details have been generalized to maintain confidentiality and prevent identification of the original case. Such generalization does not affect the scientific principles, methodology of reconstruction, calculations, interpretations, or conclusions presented in this study.

Introduction

Road traffic accidents continue to represent one of the leading causes of injury and death worldwide. Determining the speed and movement of vehicles involved in such accidents is a critical component of forensic investigation because vehicle speed frequently influences both accident causation and injury severity [1, 2].

Traditional accident reconstruction techniques rely upon tyre skid marks, yaw marks, crush damage analysis, event data recorders, and witness testimony. However, modern vehicles equipped with anti-lock braking systems frequently leave little or no visible braking evidence. In addition, electronic vehicle data may be inaccessible due to severe damage or lack of retrieval capability. Consequently, forensic investigators must often rely upon alternative physical evidence and engineering principles to reconstruct accident events [3].

One such approach involves the analysis of airborne vehicle trajectories. When a vehicle becomes airborne after interacting with a roadside structure, embankment, or terrain feature, its subsequent motion may be analysed using projectile mechanics. Once wheel contact with the ground is lost, the vehicle behaves as a projectile whose movement is governed primarily by gravity. The resulting trajectory can provide valuable information regarding vehicle velocity at the moment

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of launch [4-6].

The present study describes a unique accident reconstruction case involving an airborne vehicle trajectory generated by impact with a roadside bridge structure. The case is notable because the airborne motion was produced not by a conventional ramp but by collision dynamics associated with a relatively low roadside structure. The objective of this study is to demonstrate the application of projectile motion principles in forensic reconstruction and to estimate vehicle speed using measurable scene evidence.

Theoretical Background

Accident reconstruction is fundamentally based on application of Classical Newtonian mechanics in order to understand the real-world collision. The motion of vehicle before, during and after impact can be analysed using principles of kinematics, dynamics, conservation of momentum and energy transfer [7].

In some vehicle accidents that to be vehicle becomes airborne after impact and in the absence of traditional speed indicators, the vehicle motion can be estimated using theory of projectile motion. The projectile motion in accident circumstances defined as the motion of a vehicle after launch which moves under the influence of gravity. In the absence of significant aerodynamic effects such as considered to be air resistance is negligible, horizontal and vertical motions become independent of one another [4, 5].

During the airborne condition, the horizontal velocity component remains constant due to no substantial horizontal force affect upon the vehicle. At the same time, the vertical velocity component is controlled by gravitational acceleration. This separation of horizontal and vertical velocity components allows the forensic scientist to estimate the time of flight from the vertical drop and then estimate horizontal velocity from the measured airborne distance [8].

Projectile motion analysis has become a well-established technique in forensic engineering, transportation safety and RTA. It provides a scientifically sound approach for estimating vehicle speed, particularly in cases where conventional evidence is unavailable or insufficient to support a reliable reconstruction [9].

Case Description

The present study examines an anonymized highway accident involving a Sport Utility Vehicle (SUV). Based on the place of accident, the vehicle was travelling along the roadway on its way and then it is suddenly veered to the right lane of the road and then hit to the roadside bridge structure (The bridge is very small and its height is less than 1 feet). The height of the bridge is considered to very less that means the maximum speed was not reduced at impact point and support the vehicle to become airborne without losing much speed.

The bridge structure was approximately one less than foot higher than the roadway surface. After striking the bridge, the vehicle passed over it, lost contact with the ground, and travelled through the air before landing on lower terrain below the road level. Following the landing, the vehicle continued across uneven ground, collided with a tree, and finally came to rest after undergoing further rotational motion.

After detailed examination of place of accident it is found to be absence of skid marks or other evidence of braking on the roadway before the initial impact. The absence of such evidence made conventional speed estimation methods unsuitable. Consequently,

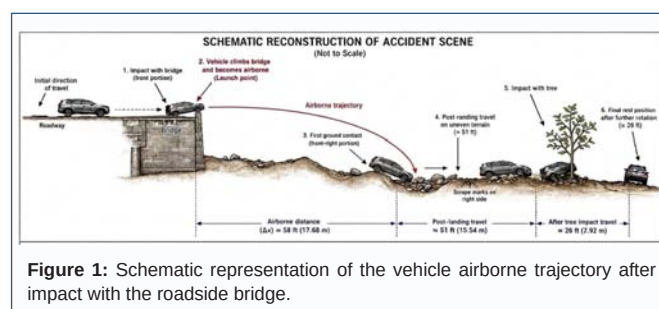


Figure 1: Schematic representation of the vehicle airborne trajectory after impact with the roadside bridge.

the vehicle's speed was estimated using the principles of projectile motion.

Scene Examination and Reconstruction of Accident Sequence

Examination of the accident scene describes that the front portion of the vehicle first hit to the road side bridge. This impact cause extensive damage to the frontal portion of the vehicle and dislodged several stones from the bridge structure. Few stones were located nearly 3 m from the point of impact indicating that the collision involved a substantial transfer of kinetic energy from the vehicle to the bridge [10].

After the impact, the vehicle climbed onto the bridge structure and became airborne. Measurements made at the scene indicated an airborne travel distance of approximately 17.68 m before the vehicle landed on terrain below the roadway level.

The damage pattern suggested that the front-right corner of the vehicle was the first part to strike the ground. Scrape marks extending along the right side of the vehicle, together with disturbances in the soil and vegetation, indicated that the vehicle rotated to the right as it continued across the uneven ground.

The vehicle then collided with a tree located further along its path. Damage to both the tree and the vehicle was consistent with a direct impact. After this collision, the vehicle continued to rotate before finally coming to rest.

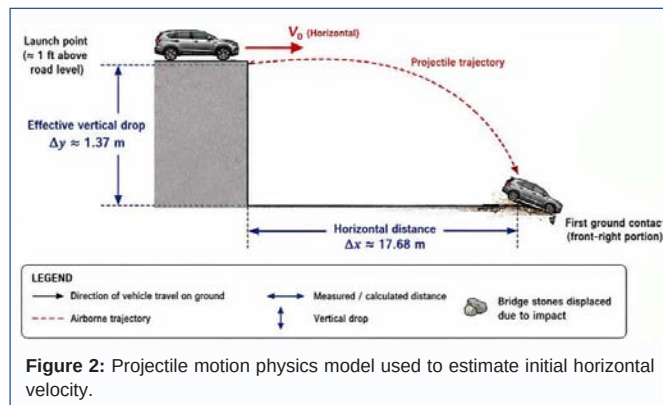
When considered together, the scene evidence supports a sequence in which the vehicle hit the bridge, became airborne, landed on the lower ground, rotated after touchdown, collided with the tree, and eventually came to its final resting position. Schematic representation of the vehicle airborne trajectory after impact with the roadside bridge was shown in figure1.

Theoretical Basis of Projectile Motion Analysis

The circumstances observed in the present case represent a classic example of horizontal projectile motion. Once the vehicle became airborne, its motion could be analysed using established principles of two-dimensional projectile mechanics.

A fundamental characteristic of projectile motion is that horizontal and vertical components of movement are independent of each other. Gravity acts only in the vertical direction and therefore influences the vertical component of motion without affecting horizontal velocity. Consequently, horizontal travel and vertical fall occur simultaneously but independently [11].

The horizontal component determines the distance travelled by the vehicle during the airborne phase, whereas the vertical component



determines the duration of flight. The common parameter linking these two motions is the time of flight.

The vehicle will continue travelling horizontally only while it remains airborne. Therefore, the time required for the vehicle to fall from the launch point to the landing point is exactly the same time available for horizontal travel. This principle forms the basis of airborne vehicle speed estimation.

The launch point was located at the bridge crest, approximately one foot above roadway level, while the landing point was approximately 4.5 feet below roadway level. The effective vertical drop was approximately 1.37 m. The measured airborne distance was approximately 17.68 m (Figure 2).

The vertical motion is governed by the equation:

$$\Delta y = v_{0y}t + \frac{1}{2}gt^2 \quad (1)$$

Assuming negligible initial vertical velocity immediately after launch ($v_{0y} \approx 0$), the equation reduces to:

$$\Delta y = \frac{1}{2}gt^2 \quad (2)$$

Rearranging gives:

$$t = \sqrt{(2\Delta y/g)}$$

Substituting $\Delta y = 1.37$ m and $g = 9.81$ m/s² gives:

$$t = 0.52 \text{ s}$$

Thus, the vehicle remained airborne for approximately 0.52 seconds.

This time represents the critical link between vertical motion and horizontal motion. During the same 0.52-second interval, the vehicle travelled the measured horizontal distance. Therefore, the horizontal velocity can be calculated using:

$$V = \Delta x/t$$

where Δx is the measured airborne distance.

The airborne time was calculated using the standard projectile motion equation for vertical displacement, assuming negligible initial vertical velocity at the instant of launch. The corresponding horizontal velocity was then determined from the measured airborne distance divided by the calculated time [12-15].

Mathematical Modelling and Speed Estimation

The measured airborne distance was approximately 17.68 m.

Using:

$$V = \Delta x/t$$

$$V = 17.68/0.52$$

$$V = 34 \text{ m/s}$$

Converting to kilometres per hour:

$$V = 122.4 \text{ km/h}$$

This value represents the approximate velocity of the vehicle immediately after launch.

Because field measurements contain inherent uncertainties and because minor vertical launch components may have been present, the result is more appropriately expressed as a practical speed range rather than a single value.

Accordingly, the post-impact speed of the vehicle is estimated to lie within the range of approximately 120-130 km/h [15].

Discussion

The calculated speed is consistent with the physical evidence present at the place of incidence, damages found on the vehicle, displacement of bridge stones, scratch marks observed on the vehicle. The displacement of bridge stones found at several metres from the point of impact suggesting transfer of substantial energy at the time of collision. Likewise, the ability of the vehicle to climb the bridge structure and subsequently travel approximately 17.68 m through the air indicates the presence of significant residual momentum following impact.

The landing dynamics provide additional support for the reconstruction of accident scene. Based on the damage portion of the vehicle at the front-right portion clearly suggest the vehicle was landing like a nose-down landing configuration. Then further the vehicle continued travel across uneven terrain and extensive scraping at right side driver door portion with eventual impact with a tree. This information collectively demonstrate that considerable kinetic energy remained after completion of the airborne phase.

The major disadvantage in this accident scene is absence of visible braking evidence, skid marked and braking marks. The absence of these marks may due to the anti-lock braking systems be able to reduce skid mark formation or the complete absence of tyre marks suggests that no substantial braking was applied by driver before impact. Consequently, the actual vehicle speed before collision should be greater than the estimated post-impact velocity due to the small amount of energy have been dissipated during the bridge impact.

The case is particularly noteworthy because the vehicle became in airborne phase after collision which is associated with a relatively low height roadside structure rather than a conventional ramp. This unusual mechanism demonstrates the importance of considering roadside infrastructure characteristics during forensic accident reconstruction.

Limitations

This reconstruction was carried out using the physical evidence available at the accident scene together with established principles of classical mechanics. As with any reconstruction, the findings are subject to certain limitations. The estimated speed corresponds to the vehicle's velocity after it struck the bridge and therefore should not

be interpreted as its exact speed before impact. No electronic vehicle data, Event Data Recorder (EDR) records, or reliable eyewitness information were available to independently verify the reconstruction. In addition, the calculations assume ideal projectile motion and do not explicitly account for factors such as aerodynamic drag, small changes in launch angle, or local variations in the landing terrain. Even so, the estimated speed is consistent with the scene evidence and provides a reasonable explanation of the vehicle's observed trajectory.

Conclusion

The present study demonstrates the successful application of projectile motion analysis to the reconstruction of an unusual airborne vehicle accident. Examination of physical evidence indicated that the vehicle became airborne after impacting a roadside bridge structure and subsequently travelled approximately 17.68 m before ground contact. Application of free-fall and projectile motion principles yielded a calculated post-impact velocity of approximately 122.4 km/h. Considering uncertainties associated with field reconstruction, the vehicle speed was estimated to lie within a practical range of approximately 120-130 km/h. The findings illustrate the evidential value of forensic physics in accident reconstruction and demonstrate how airborne trajectory analysis can provide scientifically defensible conclusions when conventional speed indicators such as skid marks and electronic vehicle data are unavailable.

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