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A PERSON FALLS FROM A WINDOW

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The death of a person who dies by falling from a window may often be considered a suicide, unless it is quite evident that the fall was accidental or homicidal. If a possible defendant is questioned and he insists that the death is a suicide, the probability of his being brought to trial is remote. If he is tried, he will be acquitted in many cases. The evidence which could be used in order to prove a defendant guilty involves the use of the physical *laws of motion.*

The author made a series of experimental studies in order to obtain pertinent data with which to implement these physical laws of motion in terms of the demands of evidence in two possible cases. This article is a report of these studies and an explanation of how the laws of motion may be combined in a single equation of practical value for use in the investigation of a fall from a window.

FIRST CASE

A husband and wife attended an evening party where they began to argue. By the time they arrived at their second-floor apartment, after midnight, the husband was so emotionally disturbed that he began beating his wife with his fists—mostly about the head. This took place in their bedroom, which overlooked a street. The head board of the fullsized bed was at an angle across the right-hand corner of the room, facing the street. The one side of the head board was at the right side of a front window and the other side was against the side wall. There was only a distance of 11 inches between the midline of the window and the bed. This narrow space left no opportunity for free motion of the body, except from the hips up. The window sill and the bed were practically on the same level.

When the police arrived the wife had gone through the window, landed on the street, and had been taken to a hospital. There was blood in the street, at the curb, indicating the place where the victim had landed. This place was not directly in front of the window, but 85 inches to the left of the midline of the window as one looked out on the street from the bedroom. The normal horizontal distance from the curbline to the front wall of the apartment biulding was 95 inches. Thus, the diagonal horizontal distance from the midline of the window to the place of the victim's landing was 127 inches, or 10.6 feet. The ratio of 95 inches to 127 inches is the cosine of the angle this horizontal diagonal makes with the normal to the window. The angle, 41°, is obtained by referring this cosine value to a table of trigonometric functions. This angle and these distances are most unique evidence that the wife did not go through the window by her own efforts. If she had jumped from the window sill, it would have been impossible for her to have attained the speed necessary in order to land where she did. The wife was of a size and weight which the husband could lift and swing in an arc as he stood in the narrow angular space between the bed and the window.

Let us determine what the wife's *speed* was as she left the window. It is assumed that this speed is in the horizontal direction. Assuming the speed to be in any other direction would lead to a more complex solution having no purpose. It may be shown that an object falls from rest in the same time, for a given height, as it does if it starts from this height with a horizontal velocity. Since this is true, we can find the time of the wife's fall by using the equation for an object falling vertically from rest. The equation is:

$$s = \tfrac{1}{2} g t^2$$

where s = vertical distance from exit point of window to gutter, 15 ft.
g = gravitational acceleration of the body, 32.2 ft/sec^2
t = time of fall in seconds

Substituting values and solving for the time, t = 0.97 sec. Since the horizontal speed remains constant from the window to the gutter as the fall takes place, this speed is equal to the horizontal distance covered by the fall, 10.6 ft. (as found above) divided by the time, 0.97 sec., or 11 ft/sec.

What if the husband insisted that he had no part in his wife's plunge through the window? In order to contradict this assertion it is necessary to show that the wife could not have taken off from the window, or even the bed, and have attained the speed of 11 ft/sec. This has been difficult to do because of a lack of experimental proof. For this reason the author turned to the data of the running broad jump, 1923–1962, for United States Women Champions.[1] In this event the jumper runs 60 or more feet, gaining speed as she runs, to a take-off board level with the ground, where the direction of the motion is changed by the thrust of one of the runner's legs. The thrust introduces a vertical component to the jumper's speed, so that the tangential speed of the jumper at the take-off from the board consists of horizontal and vertical components. While the ideal angle of take-off is 45°, coaches have found that an angle of 40° is the usual angle[2], and it is the one used for calculations in this study.

The motion of the jumper in the air is comparable to that of a projectile. This makes it possible to calculate the tangential speed for the take-off, knowing the horizontal distance of the jump and the take-off angle, 40°. The tangential speed for each jump made by the United States Women Champions, 1923–1962, was calculated and multiplied by cos 40°, in order to obtain the horizontal component. A mean was found by adding the horizontal components and dividing by the number of jumps. This value was 18.54 ft/sec and the standard deviation was 0.61.

Each contestant had trained rigorously for this event, part of the training being to determine the shortest distance within which she could achieve maximum speed and still be prepared for the jump. Coaches for this event have found that the average shortest distance is 60 ft.[3] If the maximum horizontal speed attained in 60 feet is considered to be 18.54 ft/sec, the runner's acceleration is equal to the square of the velocity $(18.54)^2$ divided by twice the distance run (2×60), that is, 2.86 ft/sec^2. This is the acceleration for a trained athlete, not for a woman who has done little or no running in her life. There is no way of knowing what the maximum acceleration would be for a woman who has had no experience in running. Such knowledge, however, is not necessary in a case such as the one which is being considered here. It is sufficient to show that if the wife had had an acceleration of 2.86 ft/sec^2, she would have had to run a distance of 21.2 feet in order to attain a speed of 11 ft/sec at the window. The distance, 21.2 feet, is found by dividing the square of the speed by twice the acceleration. It was not possible to run this distance in the small bedroom. For an acceleration of less than 2.86 ft/sec^2, the distance required in order to attain a speed of 11 ft/sec would have had to have been greater than the 21.2 feet. In this way the acceleration derived from the data for United States Women Champions in the running broad jump has been used to contradict the husband's disclaimer that he had nothing to do with his wife's death.

It has been shown that the wife traveled along a window-to-street trajectory which made an angle of 41° with the normal to the window. For such an angle as this the virtual width of the window sill becomes greater than the actual width, involving not only a diagonal width of the sill but also the shoulder width of the person moving over the sill. It may be shown that this virtual width is equal to the shoulder width of the victim times tan A plus the actual width of the sill divided by cos A, where A in this case is 41°. Considering the shoulder width to be 15 inches and the sill width to be 12 inches, the virtual width is 29 inches, or 2.4 feet. This distance is significant because the wife would have had to have cleared it if she had gone through the window by her own efforts. During the entire time that the wife was airborne from the window to the street curb, she was entirely unable to change the direction of flight by any movements made while in flight.

The proof that the husband is untruthful in this case is possible because the height of fall and two distances on the street level are known. These three distances are used in order to calculate the *angle* at which the wife left the window, and also her *speed.*

SECOND CASE

A husband and wife were having a seemingly harmless tiff in their second-floor apartment one night when the bickering suddenly fulminated into violence. A fist flashed to the wife's head. Seeing that she was unconscious, the husband opened a

[1] FRANK G. MENKE, THE ENCYCLOPEDIA OF SPORTS, A. S. Barnes and Company, New York, 1963, pp. 977–978.

[2] DEAN B. CROMWELL, CHAMPIONSHIP TECHNIQUES IN TRACK AND FIELD, New York: 1941, p. 230; RICHARD I. MILLER, FUNDAMENTALS OF TRACK AND FIELD COACHING, New York: 1952, p. 92.

[3] THOMAS KIRK CURETON, Mechanics of the Broad Jump, SCHOLASTIC COACH, May 1935, p. 9; JOHN W. BUNN, SCIENTIFIC PRINCIPLES OF COACHING, Englewood Cliffs, N. J., 1964, p. 119.

bedroom window overlooking a parking lot of bare, hard-packed earth. Border lights made it possible for him to have a clear view of the lot. His car was parked under the window. Fearful that his wife might regain consciousness if he took time to move the car, the husband carried his wife to the window and ejected her head first, so that her head was the first part of her body to strike the ground to the right of the window. Her body cleared the car. She was visible now from a street running along one side of the lot.

The husband left the apartment and drove away for a time, leaving his wife lying on the ground where she had fallen. Upon his return the wife still lay where he had left her. He parked his car on the street, went to the apartment, and broke the glass in the lower sash of the window through which his wife had been thrown. He then took his wife to a hospital where she died.

When the husband was questioned about his wife's death, he said that he had heard a crash of glass in the bedroom while he was elsewhere in the apartment. He said that he had hurried to the bedroom and found the glass of a window broken and his wife on the ground beneath.

The only evidence of violence in the apartment was the broken window pane. Except for a dagger-like shard, 7 inches in length, which was still firmly fastened in the top of the sash, there were only very small fragments of glass left in the channel which had formerly held the pane. Small shards of glass were found on the sill and on the floor. Most of the glass was on the ground, the center of the distribution being 20 feet from the wall of the building. This kind of evidence is usually not considered to be significant because "How can one tell whether the wife or the husband broke the glass?"

In order to determine whether the wife or the husband broke the glass it is necessary to know the differentiating ways in which glass breaks when it is rammed by (1) a plunging person or (2) a swung or pushed object. The author made a study of the ways in which window glass breaks when a pendulum, with various coverings on the impact part of the pendulum, strikes the glass. New double strength, ½ inch window glass, 27 inches by 39¼ inches, was mounted in a frame rigidly fastened to a laboratory table so that the center of the glass was 59 inches above the floor. The floor in front of the glass was covered with sheathing paper marked with lines one foot apart. This served as a coordinate system, 14 feet wide and long, for locating the positions of the shards. The pendulum, mounted on the table, had a length equivalent to that of a simple pendulum of 47 inches, and weighed 49.25 pounds. This weight was concentrated in the impact portion of the pendulum. The surfaces of the pendulum, which made contact with the glass in the impacts, were three plain stainless steel, curved, polished, hub caps, 9.5 inches in diameter and 3.5 inches in depth. These were mounted as part of the pendulum's bob. The forward central cap, in the position of a head, took the brunt of the impact. The other two caps were in the position of the shoulders, the distance between their outer edges being 20.5 inches. However, it was found that the two shoulder caps encountered little glass after the head cap had gone through, so that these caps contributed nothing of significance, irrespective of the covering on them.

Before taking up the discussion of the results of this study, two statements should be made concerning the conservation of momentum, as applied to this study. While the weight of the pendulum is not comparable to that of an adult person, it can be shown that since the weight of a glass shard may be neglected in comparison to that of the pendulum in a momentum relationship, a weight greater than the pendulum would not increase the momentum of a shard. It is also true that since the weight of a shard is negligible compared to that of the pendulum, the limiting speed of a shard would be twice the speed of the pendulum at impact.

Twelve panes of glass were broken by the head cap striking against the center of the pane. The sizes, shapes, and distribution of the shards for each pane were studied, measured, and photographed. A digest of this information appears in the following statements for each of the twelve panes of glass.

Pane 1. Head cap had no covering. Impact speed was 7 ft/sec. Shards were of random large and small sizes, like those originating from window glass broken by a dense heavy object, which had been thrown or swung at the glass. Very few shards had speeds greater than 1.3 times the speed of the pendulum, and no shard had a speed greater than 1.9 times the speed of the pendulum.

Pane 2. Head cap had no covering. Impact speed was 9 ft/sec. Shards were similar to *Pane 1.* Very few shards had speeds greater than 1.2 times the speed of the pendulum, and no shard had a speed greater than 1.6 times the speed of the pendulum.

Pane 3. Head cap had no covering. Impact speed was 9 ft/sec. Shards were similar to those in *Pane 1.* Very few shards had a speed greater than the speed of the pendulum, and no shard had a speed greater than 1.8 times the speed of the pendulum.

Panes 4 and 5. Head cap was covered with eight layers of nylon stocking material. Impact speed was 7 ft/sec. The sizes, shapes, and distribution of the shards were comparable to those from the panes broken by the head cap with no covering. Very few of the shards had speeds greater than 0.9 times the speed of the pendulum, and no shard had a speed greater than 1.3 times the speed of the pendulum.

Pane 6. Head cap was covered with two layers of a heavy denim type material. Impact speed was 7 ft/sec. Most of the shards were small narrow rectangles. There were a few long strips, and there was a scattering of irregularly shaped pieces. The glass as a whole had a chopped or hashed appearance, which was very unique for this type of head covering. Very few shards had speeds greater than 0.9 times the speed of the pendulum, and no shard had a speed greater than 1.3 times the speed of the pendulum.

Pane 7. Head cap was covered the same as for *Pane 6.* Impact speed was 9 ft/sec. Shards were similar to those in *Pane 6.* Very few shards had speeds greater than 0.8 times the speed of the pendulum, and no shard had a speed greater than 1.2 times the speed of the pendulum.

Prior to the breaking of the next five panes, attempts were made to break a pane with white rabbit fur on the hub cap. The thickness of the fur was 2.2 millimeters. The pendulum was sent against the pane at speeds of 7, 8, 9, and 10 ft/sec, but the pendulum bounced back from the glass without cracking it. From this experience it might be expected that a person with a heavy head of hair would find it difficult to go through a window pane head first. Of course, glass that has been in a window for some time should break more readily than new glass.

Panes 8 and 9. Head cap was covered with white rabbit fur under a plastic rain cap. Impact speed was 7 ft/sec. Shards had a chopped or hashed appearance similar to those for *Panes 6 and 7.* The sizes of the shards varied from small peanuts to long, thin, rectangles and triangles. There were also some four-sided and irregularly shaped large pieces. Very few shards had speeds greater than 0.9 times the speed of the pendulum, and no shard had a speed greater than 1.5 times the speed of the pendulum.

Panes 10 and 11. Head cap was covered the same as for *Panes 8 and 9.* Impact speed was 8 ft/sec. Shards were the same as for *Panes 8 and 9.* Very few shards had a speed greater than the speed of the pendulum, and no shard had a speed greater than 1.6 times the speed of the pendulum.

Pane 12. Head cap was covered the same as for *Panes 8 and 9.* Impact speed was 9 ft/sec. Shards were the same as for *Panes 8 and 9.* Very few shards had a speed greater than 0.9 times the speed of the pendulum, and no shard had a speed greater than 1.3 times the speed of the pendulum.

The nylon stocking material was chosen for a head cap covering because it was tenuous and resilient, the heavy denim type material because it was dense and shock absorbent, and the white rabbit fur because it was animal hair, which proved to be highly shock absorbent. Very few shards had speeds noticeably greater than the speed of the pendulum's head cap, irrespective of the head cap's covering. This fact is *important* and is a refutation of the popular belief that as the shards fall from a window there is a ricocheting of shard on shard, with the result that the shards land farther from the window than they would have landed without ricocheting. The shards in flight have a common center known as the center of gravity. The motion of the center of gravity is the same as if all of the shards were concentrated at the center of gravity. This is a very important principle used in the dynamics of a rigid body.

Returning to Case 2, let us assume that we accept the husband's statement that he cannot be considered as responsible for his wife's death. On this premise we must conclude that the wife either plunged through the glass of the window or removed the glass in some way other than by a plunge, after which she caused herself to travel from the bedroom to where her husband found her. Recalling the fact that the center of distribution of the glass shards on the ground was 20 feet from the wall of the building, let us determine what the mean speed of the shards was as they left the window, the center of the lower sash being 16.1 feet above the ground. As may be calculated by the equation in Case 1, a shard would fall this distance in one second, so that the distance of a shard on the ground from the wall of the building would equal its speed on leaving the window. Thus, the mean speed of the shards at the window was 20 ft/sec. It would have been *impossible* for the wife to have had this speed because it was greater than the speed of any of the United States Women Champion broad jumpers cited in Case 1. (Also, the wife was wearing 3 inch heels.)

The implement which was used in order to break the glass was found to be a woman's weekender type of luggage, weighing 7.5 pounds. What could be the maximum speed this bag would have if the wife had thrust it away from herself in an attempt to break the window pane?

In order to answer this question the author had five young women who were comparable in weight, height, and age to the wife, and also three young men stand in turn at an open window, with the toe of the left foot touching the baseboard under the window, and the right foot placed to the rear and side of the left, affording a solid stance. A well braced wooden case, weighing 7.6 pounds, with dimensions comparable to those for this type of luggage was used. The right hand, holding the case by a firm handle, was level with the top of the shoulders, so that the bottom of the case faced the open window. The participants thrust the case directly forward with as much force as possible, but let go of the case when the right hand reached the plane of the lower sash. From this point the case fell to the ground. Each of the young women threw the case three times while wearing low heels, and three times while wearing 3 inch heels. Each of the young men threw the case three times. The speed of the case as it left the hand of the participant was found from the horizontal and vertical distances of the trajectory. The average speed of the fifteen throws by the young women, while wearing low heels, was 14.4 ft/sec. The average speed of the fifteen throws by the young women, while wearing 3 inch heels, was 13.7 ft/sec. The average speed of the nine throws made by the young men was 21.3 ft/sec.

For comparison purposes let the average speeds of 14.4 ft/sec and 13.7 ft/sec for the young women have a common value of 14.0 ft/sec, and let the average speed for the young men be considered as 21.0 ft/sec. If these young women and men had thrust the case from the bedroom window in Case 2, the average distance the case would have landed from the wall of the building would have been 14.0 feet for the young women and 21.0 feet for the young men. These distances can be used in order to estimate how far the glass could have traveled from the window by being pushed out by the weekender bag in the hands of either the wife or the husband, assuming that the bag had the same weight and size as the wooden case, and had a hard surface. In the study on the breaking of window glass it was found that very few shards had speeds greater than from 1.0 to 1.3 times the speed of a hard surface breaking the glass. If the wife had caused the bag to have a speed of 14 ft/sec as it arrived at the glass, very few shards would have been farther than 14 to 18 feet from the wall of the building. If the speed of the bag had been 21 ft/sec in the hands of the husband, very few shards would have been farther than 21 to 27 feet from the wall. The above speeds and distances are terse indicators that the husband, and not the wife, broke the window glass.

From measurements, it was found that the wife traveled along a window-to-ground trajectory which made an angle of 27° with the normal to the window. The virtual width of the window sill is found in the same way as for Case 1, that is, the wife's shoulder width of 17 inches times tan 27°, plus the actual sill width of 16 inches, divided by cos 27° is equal to 26.6 inches, or 2.2 feet. Aside from the impossibility of the wife having been able to send the glass as far as it was found from the window, it is just as impossible that she could have sent herself through the lower sash in any way at an angle of 27° with the glass rammed out. There was no evidence on any part of her body that she had been cut by the glass. The reason for this was that she lay on the ground to the right of the window at a sufficient distance to escape the shower of shards, the shards traveling much farther than she had.

The husband used the rock-like earth of the parking lot to kill his wife, sending her with force along an almost vertical trajectory so that her head would take the brunt of the impact. In order to establish this fact all evidence on the parking lot was located by means of a coordinate system, with distances measured from the wall of the apartment building and the street for each item. Close-up photographs were made of all evidence as it appeared on the lot. These measurements and pictures made it possible to show that the wife died through the efforts of her husband.

The Equation

The mathematics and its applications which were used in the evaluation of the evidence in the two cases considered in this article have proved to be reliable and useful in the solution of problems in motion since the time of Sir Isaac Newton. True, they have not been used in the way in which they are used in this article, but there is no basis for an argument that they cannot be applied to human trajectory problems in an attempt to determine whether a person who has fallen from a window was a suicide, or whether the person was pushed or thrown from the window.

The equations of motion may be combined in a single equation of significant worth. This equation is

$$R = 8.05\ H^2 \div aV$$

where R is the minimum distance a person would need for acceleration

H is the horizontal distance covered by the fall, known in gunnery as the range

a is the acceleration constant of a trained runner

V is the vertical distance of the fall

Thus, if the origin of the trajectory of the fall is at the window, the values of H and V are the coordinates of the end of the fall. In order to solve this equation it would be necessary to take only two measurements of distance with a tape, namely, the horizontal distance covered by the fall (H) and the vertical distance of the fall (V).

The value of the acceleration constant for United States Women Champions in the broad jump was found to be 2.86 ft/sec^2 in Case 1. The significance of this constant was discussed in that case. But since men have gone through windows, as well as women, to die under circumstances which are still a mystery, an acceleration constant for men should be available. In order to obtain this value, the author used the data for the running broad jump, 1923–1962, for United States Men Champions[4] in the same way that the data for the United States Women Champions were used in Case 1. The acceleration constant for men was found to be 4.03 ft/sec^2. Substituting the acceleration constants for women and men in the above equation and simplifying, we have

$$\text{For a woman } R = 2.82\ H^2 \div V$$
$$\text{For a man } R = 2.00\ H^2 \div V$$

In order to illustrate how these equations may be used, let us assume the following situations for (a) a woman, (b) a man:

(a) A woman is found below a hotel window. After taking measurements for V and H and substituting 24 feet for V and 16 feet for H, and solving for R, we find that she would have needed a distance of 30 feet for acceleration in the hotel room if she had been in championship form, in order to land where she did.

(b) A man is found below his hotel window. After taking measurements for V and H and substituting 50 feet for V and 27 feet for H, and solving for R, we find that the distance he would have needed for acceleration, if he had been in championship form, would have been 29 feet, in order to land where he was found.

The real significance of the acceleration distances for these two situations is that (1) they are hopelessly short for anyone but a trained runner; (2) the usual unobstructed distances in a hotel room, between a window and furniture, are far too short to permit any significant acceleration; (3) anyone but a trained runner and jumper would lose speed on arriving at a window, after a dash towards it, because of not knowing how to go from running form to diving form.

Unfortunately, a person may be considered a suicide by falling from a window because there seems to be no other evidence. On the other hand, an attempted explanation of how the suicide took place may be so ridiculous as to belie the supposition of suicide, as in the following instance. A husband reported that his wife jumped up on a bed and ran across the bed to the opposite side, from where she dived into the air to move across to the window, a distance of five feet. Arriving at the window, she went through the window-length curtains which covered the window, without disturbing the curtains, but sending the window glass flying many feet from the building. The woman was wearing three inch heels as she ran across the bed and had never participated in any sport. The short distance she had for acceleration, and the fact that window glass was found many feet from the building are both evidence that the woman did not go through the window by her own efforts.

The expert who has been engaged to give this type of testimony in court may find that he will not be permitted to testify because the court is not acquainted with the mathematics or its applications, or, if he is permitted to testify, it is only after prolonged questioning about the mathematical theory involved in the application. It is to be hoped that the day will come when an expert in trajectory problems may be permitted to testify in court in the same way as an expert in toxicology can testify today. Does a judge prevent a toxicologist from testifying because the judge knows less about toxicology than the expert does? Or, is the toxicologist required to describe details of the method used in the analysis of his sample unless challenged by the defense?

[4] FRANK G. MENKE, THE ENCYCLOPEDIA OF SPORTS, A. S. Barnes and Company, New York, 1963, pp. 932–933.