Journal of Physics Special Topics
An undergraduate physics journal

P1_7 A Close encounter of the Claus Kind

K. Roberts, N. Holt, J. Murphy, J. Tranter

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

December 18, 2020

Abstract

This paper examines the possible damage that could be caused by an errant present falling from Santa's sleigh, while at cruising altitude, onto an unsuspecting person. The results show that for the chosen present (a wooden train set) the damage caused by the impact varied greatly from no fractures, up to and including certain death due to crushing of the skull. The level of injury was dependant on the time period over which the impact occurred and the difference between no fracture and a fracture of even the strongest part of the skull was less than 10ms.

Introduction

Pandemic or not, December is Santa's busiest time of the year; with a gruelling workload ahead of him and little time for error correction. It is well known that stress and long hours spent working increase the number of mistakes that people make, and this is likely just as true for Santa and his Elves. Hence, this paper examines the possible damage that one of these errors could cause, namely, failing to ensure that all presents are secured in the sleigh and the damage that could be caused to a person struck by one that falls.

Method and Results

To begin with, data had to be gathered surrounding the conditions such an incident could occur in. Due to common portrayals of Santa not featuring an oxygen mask, it was assumed that he would be flying at an altitude of around 10,000 feet, to avoid hypoxia and other oxygen deprivation related issues that begin to occur above this height [1].

The item decided upon as the errant present was chosen to be a wooden Toy train set. This was due to its classic nature and common appearance in Christmas literature. The set chosen had a mass of 2kg and came in a box of dimensions 41.5 x 28.5 x 7.5 cm (LxWxH).

Because the present was falling from such a great height it was assumed that it would reach terminal velocity before reaching the ground. Equation 1 is the terminal velocity equation [2].

$$V_t = \sqrt{2mg/\rho A C_d} \tag{1}$$

Where V_t = terminal velocity, m = mass of the falling object, g = acceleration due to gravity, ρ = density of the fluid through which the object is falling, A = surface area of the object, C_d = drag coefficient

Taking the surface area of the present to be it's largest face area (41.5×28.5=1182.75cm^2) and using reference values for gravity (9.81m/s^2), fluid density (1.2kg/m^3) and the drag coefficient for a rectangular box (2.1)[3], the velocity of the present at the moment of impact was found to be 11.47 m/s.

This value for the impact velocity allowed the calculation of an estimated impact force for the present using equation 2 [4].

$$F_I = 2(mv/t) \tag{2}$$

Where m and v are the mass and velocity of the falling object respectively and t is the impact period. With an impact time of 0.0007s, the resultant Peak Impact Force is 65,543 N. This impact time is based on the time taken when a baseball is stuck by a bat[5]. However, there is a lot of variation in possible impact time, especially if the objects are not rigid and deform when hit. It is well known that increasing the time of a collision yields a lower impact force, hence the design of crumple zones in cars.

As such the calculations were also performed with an impact time of 0.1 seconds, a value that commonly appears in estimation calculations based on similar situations [6], where actual measurements are not feasible. This shorter impact time results in a much lower Peak Impact Force of 458.80 N. These are very different values. It is considered likely that the actual time in such an event would be closer to 0.1s than 0.0007s due to the crumpling of the person upon impact and also that in the baseball example, both the ball and the bat are in motion with greater speeds, unlike with the present approaching the stationary person. Unfortunately, there are few reference figures available for impact periods.

Discussion

To understand just how dangerous this impact would be on a human, a situation was modelled where a healthy adult would be struck on the head by the present.

The two values previously mentioned along with their mean, 33,001N, and the values halfway between the two values and the mean, 16,730N and 49,272N respectively, were compared to medical research on the force required to fracture the skull. These showed most durable part of the skull required 12,500N to fracture, with the least durable requiring 2,000N [7]. This showed that all values apart from the lowest caused a skull fracture on any region of the skull with the majority likely completely crushing the head due to the excessive force.

Rearranging the equation, it was found that the shortest impact time that would not cause any fracture (1999.99N) was 9.57ms and the largest amount of time that would fracture any part of the skull was 1.54ms.

Conclusion

It is not very surprising to find that an object dropped from a great height can cause a considerable amount of damage to a person below, even with a relatively low terminal velocity.

The fact that the margin between the impact causing essentially no damage and fracturing even the strongest part of the skull is less than 10ms (9.57 and 1.54ms respectively) was quite an interesting discovery. This result also would point to structures that are more solid facing greater impact damage than those that can deform and hence increase the impact period.

References

[1] `https://abcnews.go.com/Business/FlyingHigh/story?id=1936770&page=1` [Accessed 01/12/2020]

[2] `https://sciencing.com/calculate-terminal-velocity-6134922.html` [Accessed 29/11/2020]

[3] `www.engineeringtoolbox.com/drag-coefficient-d_627.html` [Accessed 29/11/2020]

[4] `www.gigacalculator.com/calculators/impact-force-calculator.php` [Accessed 30/11/2020]

[5] `www.acs.psu.edu/drussell/bats/impulse.htm` [Accessed 02/12/2020]

[6] `www.wired.com/2014/07/how-do-you-estimate-impact-force/` [Accessed 01/12/2020]

[7] `www.researchgate.net/publication/235623977_Strength_analysis_of_human_skull_on_high_speed_impact` [Accessed 03/11/2020]