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P5 1 Skipping Stones

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Abstract

The activity of skipping stones is put to its limits. We calculated the maximum distance a skipped stone would travel, if its flight was not disrupted by the imperfections of its interactions, on a body of still water. This was based on an analysis that used several assumptions to make the flight the most efficient. The distance we determined was approximately $34km$, which is comparatively more than the width of the English Channel.

Introduction

On the 6^{th} of September 2013, a man from Pennsylvania, set the world record in stone skipping. The man by the name of Kurt Steiner managed to skip a stone 88 times, covering a total distance of $121m$[1]. Previous research has found that a theoretical limit of skips is approximately 350[2]. This could be achieved only in ideal conditions. Let us ask ourselves, what are these conditions and how far would they allow a perfect stone to reach, if the most capable person was to perform their best throw.

Theory

The perfect stone would be light, smooth and in the circular shape with a large diameter. In order to perform many skips in series, its tilt angle must be kept constant, otherwise it will break the water surface and sink. The phenomenon responsible for maintaining that tilt angle is called 'the gyroscopic effect'. It is foundational to all spinning flights, being based on the conservation of angular momentum. Hence, having large diameter is one of the characteristics of the perfect stone. The angle of $20°$ has been determined experimentally to be the most optimal[3]. Therefore, keeping it constant by assuming no drag torque, is one of the ideal conditions.

From the theory of the projectile motion, the distance travelled in the initial stone throw is given by:

$$x_0 = \frac{v^2 \sin 2\beta}{g} \tag{1}$$

where v is the throw speed, β is the attacking angle and g is the gravitational acceleration. Each skip distance will be decreasing from this initial value as the function given by[4]:

$$\Delta x(N) = x_0\sqrt{1 - N/N_{max}} \tag{2}$$

where N is the number of skips and N_{max} is their limit. Calculating the sum of all these skip separations will give us the maximum distance travelled.

Results

The right choice of the thrower was deemed to be Aroldis Chapman, a baseball player, whose baseballs can reach $47m/s$[5]. The best value for the attacking angle was predetermined to be also $20°$[3]. This allowed to estimate the initial skip distance of $145m$, with the use of Equation 1. Next, substituting this result to Equation 2 has given us the function plotted in the figure below.

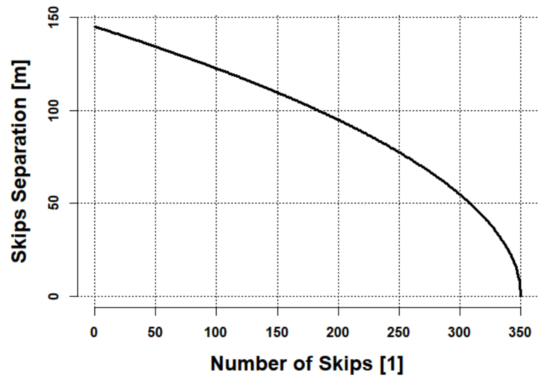

Figure 1: Skips separation distance as a function of the number of skips, given by Equation 2.

Lastly, summing all these subsequent skip separations resulted in the total distance travelled of $34km$.

Discussion

Obviously, $34km$ is an astonishing distance, however it is also unrealistic. This is due to the perfect conditions that would be impossible to achieve in reality. In our case we have no waves, no resistance forces, and no variation in angles. To improve this result, calculations can be taken that consider implications of the air drag and wave friction, which would slow down the flight speed and spinning rate. It would result in breaching the minimal speed required for a skip much earlier. Alternatively, leveling the gyroscopic effect could result in a rapid tilt angle change, that would abruptly end the stone flight under the water.

Conclusion

In summary, we calculated that a talented baseball player throwing a stone with the maximum power, the best technique, and in the perfect conditions, could skip the stone $34km$, which is enough to traverse the English Channel. It is difficult to imagine a stone making a trip over such a distance as the world is not perfect and it restrains our capabilities to skipping over ponds and lakes. Further studies could take into account the limiting factors and provide a more grounded result.

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