Knuckleball machine delivers soccer science

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Wind tunnel and high-speed camera data help researchers to explore the zigzag secrets of one of football's most unpredictable shots and provide clues to much older scientific mysteries

The zigzag trajectory of knuckleballs through the air has bamboozled goalkeepers and batsmen the world over. Scientists have been puzzled too by these strange shots and pitches, which are delivered at relatively slow speeds with little or no spin and yet travel in such an unpredictable way.

Could the seams on the ball play a contributing role? Possibly, but this doesn't explain reports of zigzag trajectories being achieved using balls without them. In a recent article published in the *New Journal of Physics*, researchers in France have developed a more universal explanation based on unsteady lift forces. Their work also addresses the question of why knuckleballs have only been witnessed in soccer, volleyball and baseball, and not in other ball games such as table tennis, squash and basketball.

To tackle the problem, the researchers - who are based at Ecole Polytechnique and ESPCI ParisTech in the French capital - used custom-built knuckleball apparatus for delivering balls at different velocities through the air. This so-called kicking machine - developed by Caroline Frot, Antoine Garcia, Caroline Cohen, and Baptise Darbois Texier of Ecole Polytechnique's Hydrodynamic Laboratory (LadhyX) - comprised an electric motor, a steel arm and a flat plate. Critically, the design allowed the scientists to launch balls with a very small amount of spin, less than a tenth of a rotation along the entire trajectory of each delivery. The group used a high-speed camera to capture the motion of each ball and employed a wind tunnel to measure air flow behaviour.

Unsteady forces

Solving the equations of motion for each dataset, the scientists found that the results obtained using the camera and wind tunnel were consistent with the presence of unsteady lift forces, but this was only part of the story. "Unsteady lift forces are inherent to balls traveling through the air in every sport, so to complete our work we needed to find out why zigzag shots are associated with just a few games, such as soccer or baseball," commented Baptise Darbois Texier.

To discover the answer, the team went back and calculated the mean lateral deviation of the ball and the typical wavelength of the corresponding zigzag path for various angles and velocities of launch. By comparing the wavelength of the zigzag path with the typical shooting distance found in each sport, the researchers were able to account for why knuckleballs are not seen in games of bocce, handball or basketball. "In bocce, for example, a zigzag path should occur over a length of 27 m, but this distance is much longer than the typical shooting length and so the knuckleball effect will be incomplete," explained Darbois Texier.

Velocity window

Furthermore, the researchers showed that even if unsteady lift forces are always present for non-spinning sport balls, there is a particular range of velocities where lift forces are larger. Under these conditions, intermittent reattachment of the boundary layer around the ball generates temporarily asymmetric forces on the object, encouraging side-to-side movement. This amplification generates the large lateral deviation in the path of the ball, which can be so confusing to opponents on the sports field. Also, the behaviour diminishes once spin is introduced, which explains why top players go to great lengths to avoid rotating the ball when attempting deliveries with a zigzag trajectory.

Older puzzles

But it's not just sports that benefit from the group's analysis. The research may also help to answer much older scientific puzzles such as why the rotation of the Earth was eventually revealed using a pendulum rather than by free fall experiments as suggested by Newton. "Any ball that you release in air will flutter after a while and produce some zigzag, which has a physical origin similar to the 'knuckleball' effects we have studied here," said Christophe Clanet, who leads the LadHyX team. "These zigzags are larger than the deviation induced by the Coriolis force arising from the Earth's rotation, which helps to explain why numerous free fall experiments failed to produce the desired results."

The group plans to examine this historical perspective in more detail in its next research article on this theme.

More information: Baptiste Darbois Texier et al. Physics of knuckleballs, *New Journal of Physics* (2016). DOI: 10.1088/1367-2630/18/7/073027

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