Case Study

Exploring material properties and Physics in Cricket

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Ansys Software Used

This case study uses Ansys Granta EduPack™, the set of teaching resources to support materials education and Ansys Fluent®, the fluid simulation software.

Summary

In this case study, a comprehensive study on the materials of a cricket ball and a bat is discussed. The resource will compare the materials of the ball with various materials with similar properties like rubber and leather using Ansys Granta Edupack Software. This will help us understand the material properties that was considered initially with the selection and design of Cricket equipment. A more comprehensive fluid dynamic study was carried out using Ansys Fluent Software on the ball to understand the physical phenomenon of the swing of the ball. We discuss the angle of attack as well as the roughness of one side of the ball as factors that lead to swing of the ball during the action. The material choice of the Cricket bat was also discussed; the properties of the Willow bat was compared with similar types of wood like maple and pine.

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1. Introduction to Cricket

Cricket is estimated to have around 2.5 billion fans, which would make it the second largest sport in the world. The earliest reference to cricket is over 500 years old but sources vary. The game's rules, the Laws of Cricket, are maintained by Marylebone Cricket Club (MCC) in London and it is now widely played, not only in the United Kingdom, but throughout South Africa, New Zealand, Australia, West Indies, India, Sri Lanka and increasingly in the US. The sport does resemble baseball in that a hard ball is bowled towards a batter who aims to hit the ball with a bat and score runs. However, this is where the similarities cease. Whereas a baseball bat is round, the cricket bat has a flat wooden surface.

The ground is set-up in a slightly eccentric circle with the middle being a hardened strip of the pitch called the wicket (the radius of the pitch varies from between 59.4 to 82.29 m) (Figure 1). A bowler over-arm bowls the ball towards the wicket (three stacked wooden stumps and bails on top of it) behind the batter, defending the wicket at the opposite end. The ball must reach the batter below a certain height and usually bounces once on the ground, adding to its unpredictable behavior. To make this a more complex task, bowlers may bowl with spin or swing. A spin bowler is essentially trying to trick the batter into hitting where the ball is not, whereas a swing bowler tries to swing the ball around the batter and into the stumps. Catchers then try to retrieve the ball. When one pictures cricket, the image of a bowler rubbing one side of the ball or giving it a 'shine' may come to mind. This is not just to make the ball look better but plays a crucial part in achieving swing.

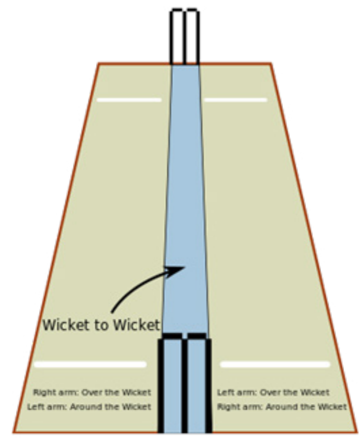


Figure 1: Schematic of a cricket pitch

A considerable part of the game is determined by the bowler and the ball's trajectory towards the batter. There are three major forces acting on the ball in flight (Figure 2). The gravity, of course, making sure the ball eventually hits the ground. The second one is the Magnus force, caused by the spin of the ball in contact with the airflow, which will bend the trajectory, similar to what we can see in tennis or football, for example. The reason for the Magnus effect is that the ball has laminar air flow on one side and turbulent on the other. There would normally be a backspin due to the rules of how to bowl, but topspin or other spin directions are possible. The effect of backspin would be to extend the length of the trajectory and a steeper bounce after hitting the ground.

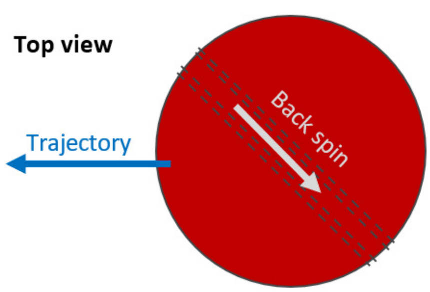


Figure 2: schematic of the trajectory and back spin forces on a cricket ball

The third force is unique for cricket and is one of the major secrets of success for the bowler. It results from the slightly protruding primary seams of the cricket ball and the angle of the spin in relation to the trajectory in combination with the speed and humidity of the air. This is also due to the ball having laminar air flow on one side and the other turbulent, caused by the asymmetry.

The type of balls used changes between the different forms of the game, leading to the vibrant color schemes of the Indian Premier league, where white balls are used in so called T20s and ODIs, to the classic and somewhat timeless red ball, being used on a small village pitch. Recently, the Test matches (5-day long format match) are increasingly played as a Day night and the use of Pink ball has been deployed for better visibility during the twilight and under the light conditions. Yet the difference in balls is not solely down to how the leather is colored but also subtleties in their manufacture. Whilst Red balls are finished with wax, white balls are coated in a harder wearing wax, as that leather is generally less durable than red leather. Pink balls are coated in polyurethane (PU). While red balls are the most durable. Both pink and white balls swing and spin more due to a combination of being more “grippy” and having a more uniform surface, owed to how the leather encasing them is sealed.

If a ball is hit particularly well, it may leave what cricketers refer to as a ‘cherry’ on the bat, a mark of the same color as the ball that was bowled. This typically occurs when the ball is struck at the ‘sweet spot’ of the bat. This transfers most of the energy back to the ball which in turn travels further. However, to limit the impulse of the bat on the ball, the governing body of Cricket set the laws so that no unfair advantage can be gained through the shapes or material of bat. Currently, the bat must be made from wood and almost all bats are made from Willow which Is attached to a cane handle.

2. Features of a Cricket Ball

2.1 Materials Selection for Cricket Ball with Ansys Granta EduPack Software

Cricket constitutes an interesting example of how materials interact with each other and are affected by their surroundings in the dynamics of a sport. We have the material surface properties on both sides of the ball and the seams, the rotation of the mass on its journey through the air flowing around it, which is affected by temperature and humidity. We also have the effects of the impact of the bat on the ball, the transfer of impulse and momentum as well as the material properties and shape of the wooden bat that will influence the trajectory towards the anticipating catchers. It is an exciting opportunity to explore the importance of material properties and the power of simulation to help understand these phenomena.

Figure 3: Inside of a cricket ball

Let us start with the cricket ball itself (Figure 3); all balls are on the inside made from a relatively firm rubber/cork composite core surrounded by thin cork layers wrapped by tightly wound woolen yarn, weighing 155.9-163 g with a diameter of 72 mm. If natural rubber is used, the ball is made of all natural materials. They are clad by two halves of thin smooth layers of cow skin (in rare cases buffalo or ox) dyed into “test match red” and fixed with a slightly raised sewn seam. The seam and the surface roughness are examples of geometrical features (shape) rather than materials and the distribution of the different materials can also be considered geometrical.

The primary material properties that might be of interest are: density, controlling the mass of the parts, bulk modulus (how stiff they will be), helping to resist deformation, and mechanical loss coefficient (tan delta) determining how much damping they will cause. A property chart (Figure 4) can help you understand and compare these parts and perhaps suggest useful replacement materials or improvements. Natural rubber (used in the core) is surprisingly stiff and dense, as is leather.

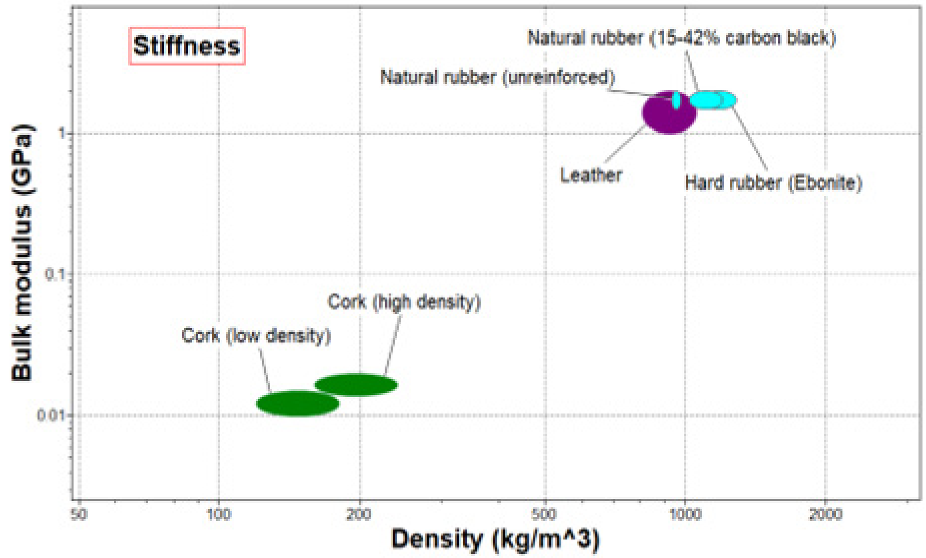


Figure 4: Bulk modulus vs. Density property chart for key cricket ball materials

When it comes to density, cork is a well-known very light-weight material, used in floating applications. This allows the cricket ball to have a relatively large size-to-weight ratio for a massive (not hollow) object and to be significantly harder than a gas-filled ball, such as those used in tennis, for example. A "first-class" (top-level) must have a circumference that is 8.81-9.00 inches or 224-229 mm, so, much lighter if it were hollow.

Looking at the damping (Figure 5), both the cork and the leather have comparable and compatible values of the mechanical loss-coefficient, or the damping coefficient, η, which is a dimensionless measure of the degree to which a material dissipates vibrational energy. The Ansys Granta EduPack software has data for several natural materials, as well as possible synthetic substitutes.

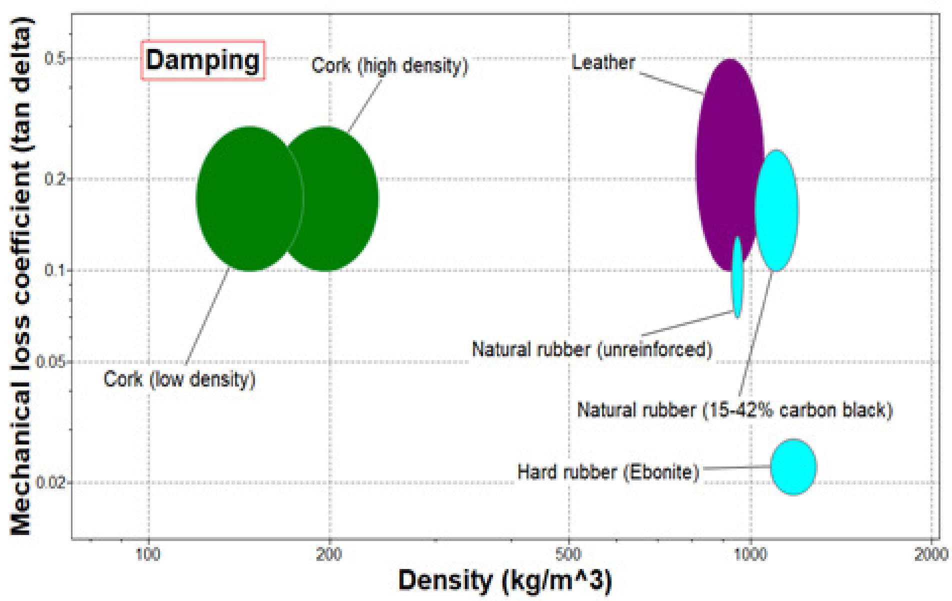


Figure 5: Mechanical loss coefficient vs. Density for key cricket ball materials

2.2 Air Flow around a cricket ball with Ansys Fluent Software

Figure 6: Cricket ball zoom in to show stitching and surface roughness

One of the main factors regarding fast bowling in cricket is the swing of the ball that the bowler extracts during the bowling action. This is achieved by maintaining the two hemispheres of the ball at different roughness (Figure 6). To create this difference, the baller uses the combination of saliva and towels. The ball, while being batted around, will have a large number of scuffs of varying sizes and shapes. This suggests that if the shine is maintained on one side of the ball, the ball will start swinging towards the rough side.

A simple simulation of the swing can be carried out using Ansys Fluent Sotware, maintaining different roughness on the two halves. We try to produce an average roughness factor on one seam side to mimic these scuffs on the ball. Ideally, there should be a net force acting in the direction of the rough surface. This acting force leads to the lateral movement of the ball which is defined as swing of the ball in cricket terminology. Here, a cricket ball of φ=36 mm is considered for the simulation at a speed of 35 m/s (approximately 80 mph, the average speed the baller balls in cricket). A simplified steady state simulation is carried out instead of transient, for simplicity. The result shows a considerable turbulence behind the ball, mostly because the ball is symmetrical about the XY plane. Figure 7 visualizes these vortices in the wake of the ball as expected.

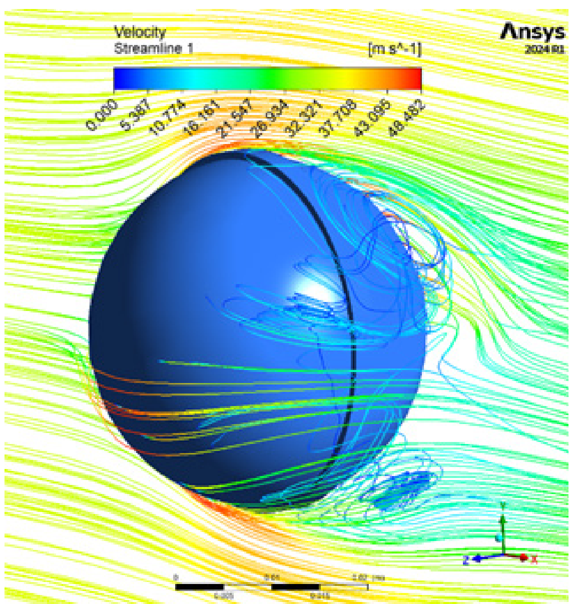


Figure 7: Results of two-sided cricket ball simulation

More detailed results will be obtained if we increase the number of cells in the simulation. But to understand the effect of roughness on the forces on the ball, we use a coarse mesh of cells close to 1 000 000 cells. The calculation was carried out for 3 different values of roughness (Table 1) on one hemisphere while keeping the other side smooth. Using the force obtained from Ansys Fluent software, we can estimate the sideways movement during the course of the ball described in this table.

Table 1: Roughness effect simulation study results

Roughness [mm]	Lateral Force [N]	Lateral Acceleration [m/s²]	Lateral Movement [cm]
0.1	0.122	0.765	12.6
0.5	0.123	0.775	12.8
1	0.147	0.926	15.3

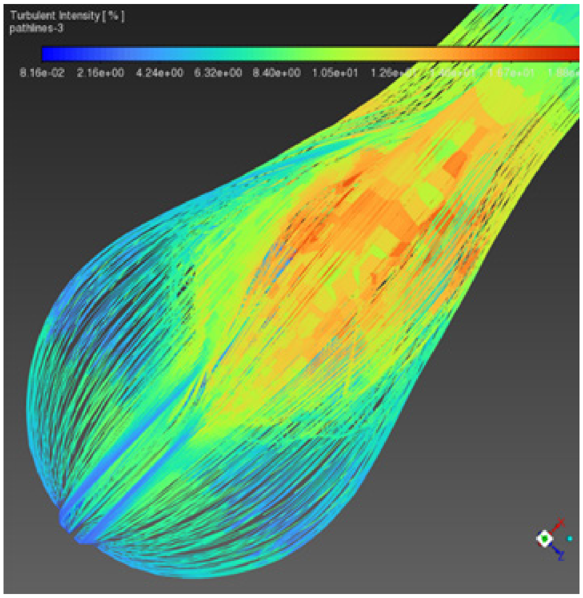
Another effect that could potentially affect the sideways movement or swing could be the angle of attack of the ball. We redid the calculation with an angle of attack at 22.5 ° to the flow of air (Table 2). This would mean there is an asymmetry in due to the seams thus leading to some swing on the ball. The simulation Is carried out and compared with a straight ball and can be seen the angle of attack could be another reason by which the ball may swing during the bowling action.

Table 2: Angle of attack simulation study results

Angle	Lateral Force [N]	Lateral Acceleration [m/s²]	Lateral Movement [cm]
0°	0	0	0
22.5°	0.02	0.1257	2.09

A detailed turbulent intensity is shown below in Figure 8 for the two cases. It is seen that there is large turbulence intensity around the angled ball compared to a ball with 0 angle of attack. This turbulence causes an uneven boundary layer, separating on both the hemispheres (which could be noticed in the figure) of the ball leading to a lateral force acting on the ball.

Thus, it is clear from the Ansys Fluent simulation software that the swing of the ball is also based on the angle of attack of the ball as well as the different roughness between the two hemispheres of the ball.



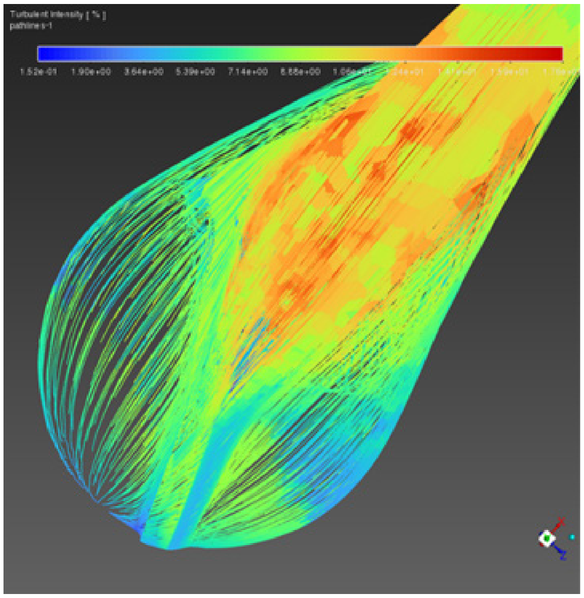


Figure 8: Turbulent Intensity path-line plot around the ball at an angle of attack of 0°(left) and 22.5° (right)

3. Material Selection of a Cricket Bat

Currently, willow is used to make wooden cricket bats, partly due to its high stiffness and its low density. Historically, the sapwood of Salix Alba has been used as bat material. This is a light-colored willow that provides more aesthetically pleasing bats. From the 1890s onward, these Willows, suitable for cricket bats, are predominantly grown in England, in Essex or Suffolk counties, but are exported world-wide. A model of the shape of a cricket bat can be found in Figure 9.

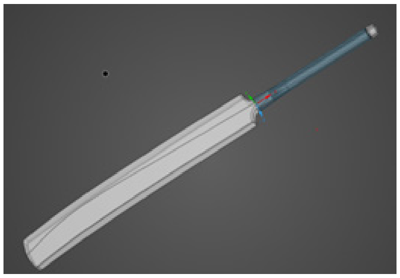


Figure 9: Cricket bat model

Marylebone Cricket Club (MCC) is the governing body of cricket that regulates Cricket bat materials by the Rules of Cricket. Law 5.3.2 states: 'The blade shall consist solely of wood'. Good quality willow takes many years to grow; high quality bats have 6–12 latewood rings, meaning that the original tree must have been at least 6 years old. It can take up to 15 years for willow trees to mature though.

Baseball bats, for example, have gradually changed over the last 100 years. Originally, they were made of wood, like hickory and were heavier than modern bats. However, throughout the 20th century, ash became more popular for making baseball bats because it offers a good balance of swing speed, weight, and durability. Cricket bats have, however, remained the same for 200 years. For the willow cricket bats, fiber and vessel cells are the largest contributors to the mechanical properties. Further processing collapses the wood cells, forming a mesh-like layer with increased hardness. Cricket bats made of willow wood need to be gently hit with a ball or mallet for several hours before being used, which is called "knocking in". This process makes the wood harder and stronger, not unlike work-hardening of metals.

Alternative materials would include hard-woods, such as oak or even bamboo, as a radical suggestion. Bamboo is a grass, so it has parenchyma and fibre cells leading to a raw material with a higher density than that of willow, once hollowness has been accounted for. It is, however, not a wood and thus not allowed.

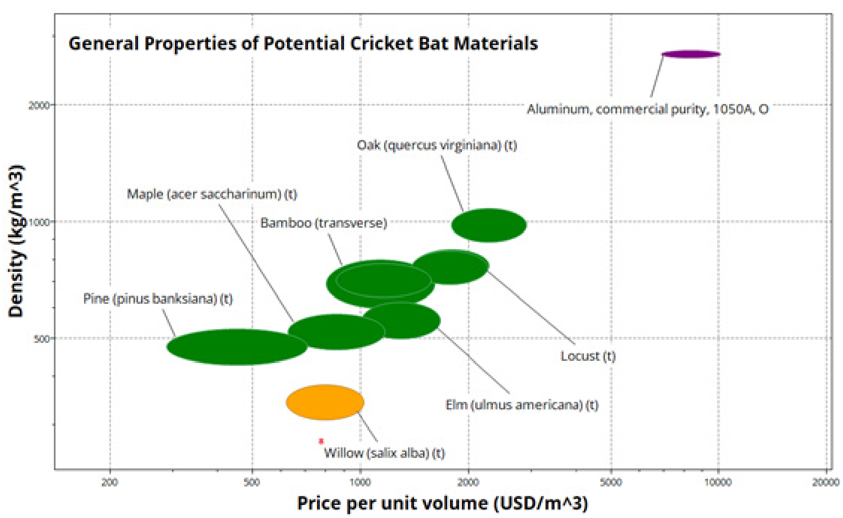
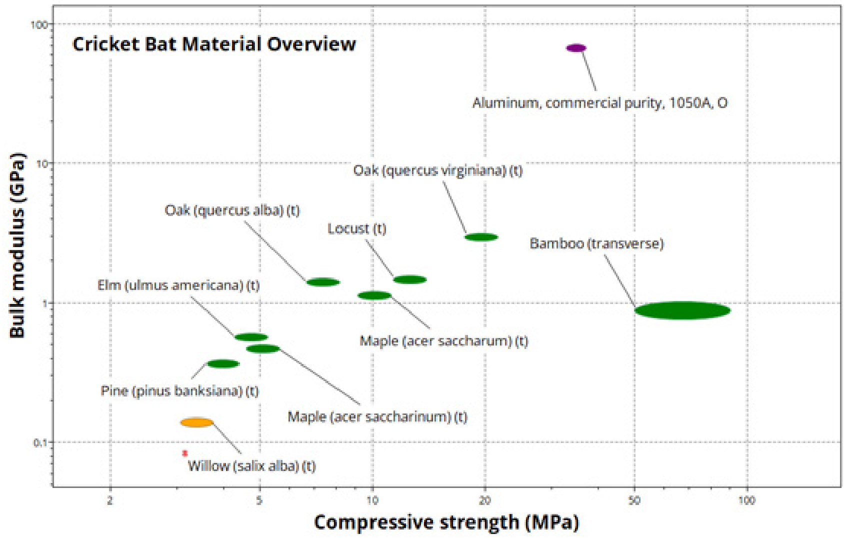


Figure 10: Density vs. Price per unit volume comparison for cricket bat materials

Compared to willow bats, bamboo bats would have good material properties, though, as shown in Figure 10. Relatively cheap and quick to produce due to a maturing age of 5–6 years. They would be stiffer and heavier. A bamboo bat, with the same dimensions as a willow bat, would be around 40% heavier. So, this allows for a thinner more easily swung bat made of bamboo. Additionally, a bamboo bat would have a larger sweet spot on the blade than a traditional willow bat. A heavier bat can generate more kinetic energy, making it better for hitting the ball longer distances, but it may sacrifice control.

As can be seen in the Figure 10, Bamboo is a denser and more expensive alternative than willow. Pine and some types of Elm would have similar compressive strength as willow in the transversal direction (t), as can be seen in Figure 11, whereas Maple, Oak or Locust would all be stronger and stiffer.

Figure 11: Bulk modulus vs. Compressive strength comparison for cricket bat materials



Willow wood is strong, shock-resistant, and lightweight, which is essential for cricket bats that are wider than baseball bats. According to Ben Tinkler-Davies, a materials scientist at Cambridge University, it is crucial for a bat to have good aesthetics and to produce a satisfying sound when hitting the leather ball. Tinkler-Davies[1] has tested the sound of bamboo bats and found that they make the same sound frequency as willow bats, which cricket fans and players love. Aluminum as a bat material, included for comparison, has been used notoriously by Dennis Lillee in a test match 1979, but it was claimed that the alumium bat was damaging the ball, so it was banned.

5. Summary and conclusions

In this case study, we have explored how Ansys software can be used to investigate topics that might be of interest to students. In this case, the hugely popular world of Cricket. Ansys Granta Edupack software with its databases can supply overviews and information about material properties while Ansys Fluent software provides details about shapes and geometry, or in this case, ball trajectory. Together, they give a picture of how software can aid the understanding of physical processes, such as bowling and batting a cricket ball, which is a complex event. Hopefully, you can take these examples and find them useful to engage students of all types of stages. The sections inside details the capabilities for material overviews, comparative visual diagrams and illustrative simulations that reveal the driving forces for the non-trivial motion of the ball.

1 Replacing willow with bamboo in cricket bats, Ben Tinkler-Davies, Michael H Ramage and Darshil U Shah, Proc IMechE Part P: J Sports Engineering and Technology DOI: 10.1177/17543371211016592.

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