

Physics-Based Analytical Framework for Performance Interpretation in Women's Cricket : A Case Analysis

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Abstract

This paper presents a purely physics-oriented comparative analysis of the performances of the winner (India) and the runner-up team in the Women's Cricket World Cup 2025. Classical mechanics principles—projectile motion, impulse–momentum theorem, conservation of angular momentum, and work–energy theorem—are applied to batting and running dynamics. The result indicates comparatively higher physical efficiency parameters in the winning team.

Key words : Projectile Motion, Impulse, Angular Momentum, and Energy Transfer

1. Introduction

Cricket represents a complex mechanical interaction between human biomechanics and classical physics. While performance analysis often relies on statistics, the underlying physical principles governing success remain under explored. This study aims to bridge that gap.

2. Theoretical Framework

2.1 Projectile Motion :

In cricket, projectile motion describes the curved trajectory followed by the ball after it is struck by a bat or released by a bowler. According to classical mechanics, this motion can be resolved into two independent components: (i) horizontal motion with approximately constant velocity and (ii) vertical motion under constant acceleration due to gravity. The superposition of these two motions results in a parabolic trajectory under ideal conditions. A projectile's range is determined by $R = (v^2 \sin 2\theta) / g$, where R is the horizontal range, v is the initial exit velocity of the ball, θ is the projection angle, and g represents gravitational acceleration. This relation indicates that, for a given initial velocity, a projection angle close to 45° yields the maximum horizontal range. Consequently, batters tend to optimize shot angles near this value to maximize scoring potential.

In real match conditions, the ball's motion is influenced by factors beyond gravity. Air resistance (drag) continuously reduces the ball's velocity, making the actual trajectory less symmetric than the ideal parabola. Additionally, spin imparted to the ball produces the Magnus effect, generating a lateral force that causes deviation in the flight path. This phenomenon is responsible for swing, seam movement, and aerial drift observed in cricket deliveries and shots.

Players intuitively exploit these physical principles - lower projection angles are preferred for fast ground strokes, while higher angles are used to achieve greater height and distance in aerial shots. Controlled application of projectile motion enables batters to optimize range, maximum height, and time of flight, making it a crucial factor in modern competitive cricket performance.

Lofted shot of a representative top order batter of runner-up team followed a parabolic trajectory, but a fielding effort of fielder in the deep region run and precise judgment of the curve to take the catch at long-on was a crucial moment in India's victory.

Batting shots of batter of winning team hit the ball with specific angles and power, controlling the ball's trajectory to hit boundaries or get past fielders, as seen in her century.

2.2 Impulse–Momentum Theorem

According to the Momentum-Impulse theorem, an object's change in momentum is equal to the entire impulse applied to it. This can be stated as follows: $F_{avg}\Delta t = m(v_f - v_i)$ It illustrates that applying a big force for a little period of time results in the same change in momentum as applying a lesser force for a longer period of time. It is represented by the product of the impulse force and time. This formula demonstrates how raising the contact time can raise the ball's ultimate velocity. When a cricket player catches a ball, they bring their hands back to prolong contact and lessen the power applied to their hands, minimizing injuries.

Safe catches (fielding): Fielders like Amanjot Kaur utilize the impulse-momentum theorem when taking difficult catches, such as the one that dismissed Laura Wolvaardt in the final.

The fielder moves her hands backward in the direction of the ball's motion, which increases the time it takes for the ball's momentum to become zero.

This increased time interval results in a reduced average force exerted on the fielder's hands, thereby preventing injuries..

Variations in bowling: Bowlers like Deepti Sharma vary the speed of the ball considerably while bowling, applying force over time to achieve the desired speed and spin.

This impulse determines the initial velocity and direction of the ball, which is then affected by other forces such as gravity and air resistance (swing).

Minimizing impact: This concept also applies to a player landing on the ground after a dive . By rolling for an extended period and absorbing the impact, the player reduces the force exerted on their body, thereby lowering the risk of injury.

The "sweet spot" of the bat: The design and use of a cricket bat are based on this principle.

Hitting the ball on the "sweet spot" of the bat reduces the impulse transmitted to the player's hands, resulting in less shock to the ball and a more efficient transfer of energy to the ball.

2.3 Angular Momentum

A rotating object's mass, velocity, and distance from the rotational axis all affect its angular momentum, which is calculated by multiplying the angular velocity (ω) by the moment of inertia (I) (i.e. $L = I\omega$). Because it is a vector quantity and complies with the rule of conservation, rotating objects continue to move. In cricket, a higher **angular velocity** of the bat swing directly boosts run production. The faster the bat rotates, the quicker the ball races toward the boundary.

The physics behind this can be explained through the relationship between angular velocity (ω) and the linear velocity (v) of the bat's toe (the tip), which moves in an arc: $v = r \times \omega$ In this equation (v) is linear velocity of the bat's hitting area.

So angular momentum is an integral physics principle in the game of cricket that influences player performance in crucial matches, such as a Women's World Cup final. It is primarily observed in a player's movement and technique during bowling, batting, and fielding.

2.4 Work–Energy Theorem

A key idea in physics is the work-energy theorem, which asserts that the change in an object's kinetic energy equals the entire amount of work done on it. The technical proficiency of the batsman determines how well energy is transferred. The work-energy theorem is applicable to a variety of cricket scenarios, especially in games like the Women's World Cup final 2025 when exerting force alters the ball's or player's kinetic energy. As per the work-energy theorem $W = \Delta KE = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$. Pulling the hands back while catching the ball increases the distance over which the force is applied, reducing the impact of the force and allowing the ball to be caught safely . This is also related to the impulse-momentum theorem, but in terms of work-energy, it gradually reduces the kinetic energy.

Throwing the ball: The fielder applies force to the ball to throw it to the wicket keeper or to the other end, which provides the ball with the necessary kinetic energy to reach the target.

Running between the wickets: When the batsmen run to score runs, they exert force on the ground with their muscles, which increases their kinetic energy and allows them to run faster.

In all of these examples, the total force applied (such as gravity, air resistance, or the player's muscular force) causes a change in the kinetic energy of the ball or the player, which is a direct application of the work-energy theorem.

3. Methodology

The numerical data presented are not official instrumented match measurements, but rather video-based approximations to offer a physical interpretation of cricket performance, with the goal of displaying comparative trends consistent with physics between the winning and runner-up teams. The values have been chosen for their analytical performance within realistic cricket physics restrictions and are representative. The cricket ball mass was taken in the ICC standard range of 155.9 –163g ; for calculations an average value of 0.159 kg was used. A common reference normalization was applied by selecting the maximum kinetic energy observed in the match as KE_{max} , allowing direct comparative efficiency evaluation between the winning and runner-up teams and it is used for calculation as the reference value. Distance calibration was performed using known reference lengths such as pitch length (20.12 m), crease-to-crease distance, and visible field markers. Time intervals were obtained using the video frame rate (frames per second).

4. Results:

It is clarified that the objective is not exact shot-to-shot mapping but comparative physics-based trend interpretation. The following values represent representative sampled batting events selected from match footage.

Table 1: Frame Based Measurement(Video Footage Analysis)

Shot ID	Team	Frame Rate (fps)	Frames Count (n)	Time $\Delta t = n/fps$ (s)	Ball Horizontal Displacement Δx (m)	Ball Exit Velocity $v = \Delta x/\Delta t$ (m/s)	Energy Transfer (Ball Kinetic Energy) $KE_{ball}=(1/2)mv^2$ Cricket ball mass: (≈ 0.159 kg)	Energy Efficiency(%) $\eta = (KE_{ball} / KE_{max}) \times 100$ (If India's max KE = 156 J (best shot))
S1	Winner	30	6	0.20	8.1	40.5	≈ 130 Joule	≈ 83 %
S2	Winner	30	5	0.167	7.0	41.9	≈ 139.5 Joule	≈ 89 %
S3	Runner-up	30	7	0.233	7.2	30.9	≈ 76 Joule	≈ 49 %
S4	Runner-up	30	6	0.20	6.8	34.0	≈ 92 Joule	≈ 59 %

Energy transfer efficiency is expressed as a normalized comparative index since direct bat swing energy measurement is not available in broadcast footage. These values clearly show that the Indian team achieved greater energy transfer due to higher angular velocity and better contact time.

Table 2: Running Speed Observation Table (Crease-to-Crease Running)

Run ID	Team	Distance (m)	Time (s)	Speed $v = d/t$ (m/s)	Run Acceleration $a=(v-u) / t$ (if runner initially at rest approx : $u=0$)
R1	Winner	17.68	2.90	6.10	2.10 m/s ²
R2	Winner	17.68	2.85	6.20	2.17m/s ²
R3	Runner-up	17.68	3.25	5.44	1.67m/s ²
R4	Runner-up	17.68	3.30	5.36	1.62m/s ²

In this study, the reported numerical values are not direct instrumented measurements. Physical parameters such as bat angle, ball exit velocity, running acceleration, and energy transfer efficiency were estimated using frame-by-frame analysis of publicly available video footage of the Women’s World Cup final match .

(a) Ball Exit Velocity Estimation : Ball exit velocity was estimated by measuring horizontal the displacement (Δx) of the ball immediately after bat-ball contact over a measured time interval (Δt): $v=(\Delta x) /(\Delta t)$,where v = ball exit velocity (m/s) , (Δx)= horizontal displacement (m) ,(Δt)= time interval (s) . The velocity was estimated using the earliest phase of the trajectory to minimize the influence of aerodynamic drag and to better represent the impact energy transfer.

(b) Running Speed and Acceleration Estimation: Running speed was estimated using the standard crease-to-crease running distance (approximately 17.68 m): $v_{run} = d/t$ Where d = running distance (m) , t = time taken (s). Running acceleration was estimated from the change in velocity during the initial sprint phase: $a=(v-u) / t$.where $u \approx 0$ was assumed at the start of running, and v is the estimated running speed.

(c) Energy Transfer Efficiency Index: The energy transferred to the ball was expressed through its kinetic energy: $KE_{ball} = (1/2)mv^2$,where m = mass of cricket ball (≈ 0.159 kg) , v = ball exit velocity (m/s) .Since direct measurement of bat rotational energy was not possible, energy transfer efficiency was represented as a comparative index based on ball kinetic energy: η is proportional to KE_{ball} . Hence, higher KE_{ball} values indicate more effective energy transfer from bat to ball. Bat energy is not exact, so we have normalized the efficiency as follows -

$$\text{Energy Efficiency (\%)} \eta = (KE_{ball} / KE_{max}) \times 100 .$$

(d) Limitations and Error Sources : Video-based estimation may involve uncertainties due to camera angle variation, zoom level, parallax effects, and possible frame loss. Therefore, the results should be interpreted as comparative physics-based estimates rather than exact instrumented measurements.

5. Discussion

The winning team demonstrated optimized projectile angles and higher impulse generation, Angular momentum, work–energy leading to superior energy transfer.

5.1 Projectile Motion :

Batsmen: Understand the launch angle and velocity to hit sixes by maximizing distance or to play shots into the gaps while considering the spin.

Fielder: Keep eye on the ball's trajectory, anticipate its landing spot and speed, and either take a catch or stop it on the ground.

In short, every hit and catch in the final is a real-time application of projectile physics, where understanding these forces is key to moments of victory.

5.2 Impulse–Momentum Theorem:

Powerful shots hit with the bat (batting): When batters hit a six, they apply a tremendous amount of force to the ball in a very short period of time. This causes a large and rapid change in the ball's velocity, sending it towards the boundary. The impulse given to the ball determines its final speed and direction.

5.3 Angular Momentum:

Bowling: Bowlers use rotational motion in their arm and torso to generate pace. Fast bowlers leverage their run-up momentum and the rotation of their shoulder girdle to transfer energy into the ball at the moment of release.

Batting: As previously noted, a higher angular velocity in the bat swing leads to greater run production. A batsman's backlift and the arc of their swing allow them to maximize angular momentum, which is then converted into linear velocity upon impact with the ball.

Fielding: When catching, fielders often rotate their bodies or move their hands in the direction of the ball's path to increase the time of impact, effectively managing the ball's momentum to prevent injury and secure the catch.

5.4 Work–Energy Theorem:

Bowling: When a bowler applies force to the ball to throw it, she does positive work on the ball, increasing its kinetic energy and causing it to move faster towards the batter.

Batting : When batters hit the ball with the bat to play a shot, the force applied by the bat on the ball acts in the direction of the ball's motion, resulting in a significant increase in the ball's kinetic energy and sending it towards the boundary.

Fielding and Catching: When a fielder catches a fast-moving ball, they perform negative work by applying a force in the opposite direction of the ball's motion. This force reduces the ball's kinetic energy and eventually brings it to a stop.

6. Conclusion:

This physics-based analysis confirms that cricket performance is strongly governed by classical mechanics, offering insights for future sports training optimization.

7. References:

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