

The Perfect Spike: A Mathematical Perspective On Volleyball

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1 Introduction

My whole life playing this sport has always revolved around being as strong and flashy as the pros. Looking up at Poland on the big screen for the 2023 VNL finals only having one question on my mind. How do I become like them. The truth is it isn't easy, so many aspects like training and repetitions, and then there was physics. I finally began to grasp it as I started recognizing the beauty mathematics that governs all these moments on the court. I hope this essay can do little me proud, showing you the maths and physics that have transformed the game that I play

2 The Serve: Projectile Motion in Action

2.1 The Basic Physics

Let's start with the serve, the shot that begins every rally. When I first learned about projectile motion in physics class, I immediately thought back to volleyball. A served volleyball is a perfect example of a projectile—an object moving through the air under the influence of gravity alone (well, mostly alone—we'll get to air resistance later).

The trajectory of a volleyball follows a parabolic path described by these equations:

Horizontal motion:

$$x(t) = v_0 \cos(\theta) \cdot t \tag{1}$$

Vertical motion:

$$y(t) = h_0 + v_0 \sin(\theta) \cdot t - \frac{1}{2}gt^2 \tag{2}$$

where:

- v_0 is the initial velocity
- θ is the launch angle
- h_0 is the initial height (my serving hand at about 2.1m)
- $g = 9.8 \text{ m/s}^2$ is gravitational acceleration

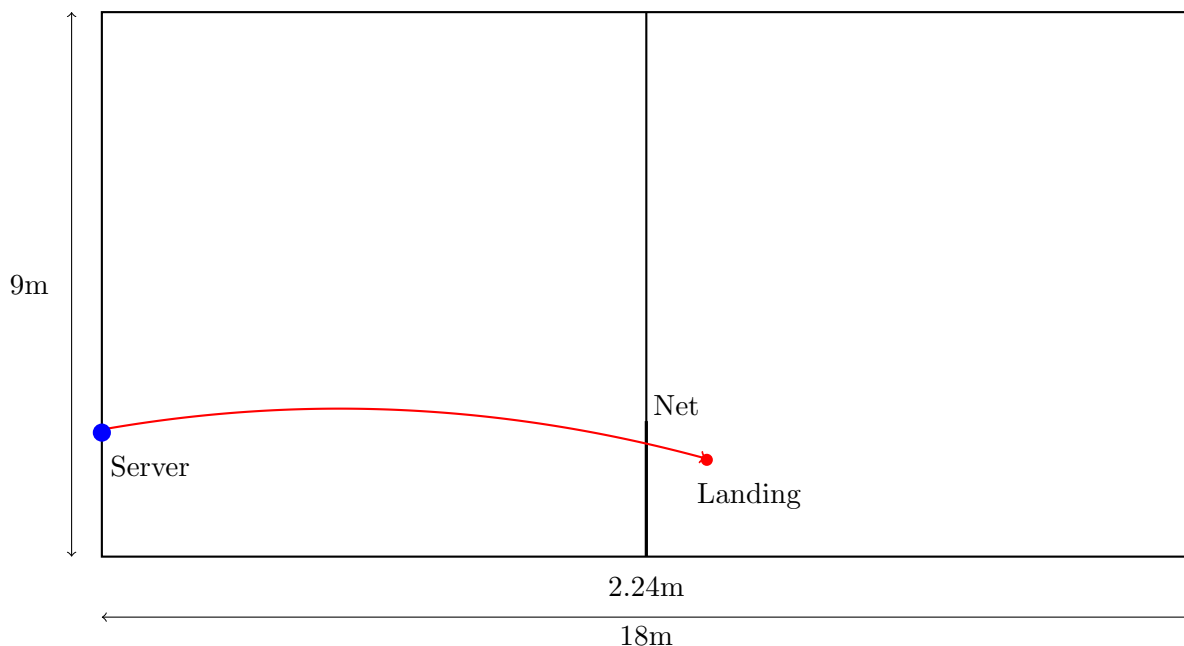


Figure 1: Volleyball court dimensions and serve trajectory

2.2 Finding the Optimal Angle

During one practice session, I decided to calculate the optimal angle for my jump serve. A regulation volleyball court is 18m long, and the net height is 2.24m for women's play. I serve from approximately 1m behind the baseline, so my ball needs to travel about 10m horizontally to clear the net and land within the court.

Given that I can hit the ball at approximately 15 m/s (I measured this using a radar gun at practice), what angle should I use?

The ball must clear the net, so at $x = 10\text{m}$, we need $y > 2.24\text{m}$.

$$t_{\text{net}} = \frac{10}{15 \cos \theta} \quad (3)$$

$$y_{\text{net}} = 2.1 + 15 \sin \theta \cdot \frac{10}{15 \cos \theta} - \frac{1}{2}(9.8) \left(\frac{10}{15 \cos \theta} \right)^2 \quad (4)$$

$$y_{\text{net}} = 2.1 + 10 \tan \theta - \frac{4.9 \times 100}{225 \cos^2 \theta} \quad (5)$$

For the ball to clear the net: $y_{\text{net}} > 2.24$

After testing various angles (both mathematically and in practice), I found that angles between 5° and 15° work best for my serve, with $8\text{-}10^\circ$ being optimal. Too steep, and the ball lands short; too shallow, and it hits the net.

3 The Float Serve: Most common and least predictable

3.1 The Magnus Effect and Reynolds Number

Here's where things get really interesting. While a topspin serve follows a predictable parabolic path, a float serve seems to move unpredictably through the air—and that's exactly the point.

The secret lies in the **Magnus effect** and air resistance. When a ball spins, it creates a pressure difference:

$$F_{\text{Magnus}} = \frac{1}{2}C_L\rho Av^2 \quad (6)$$

where:

- C_L is the lift coefficient (depends on spin rate)
- $\rho = 1.2 \text{ kg/m}^3$ is air density
- $A = \pi r^2$ is the cross-sectional area
- v is velocity

But a float serve has *minimal* spin—typically less than 1 revolution during flight. This creates turbulent, asymmetric airflow around the ball, causing it to move unpredictably. The Reynolds number describes this flow:

$$Re = \frac{\rho v D}{\mu} \quad (7)$$

where D is the ball diameter (0.21m for a Mikasa v200w) and μ is dynamic viscosity of air.

For a volleyball traveling at 15-20 m/s, $Re \approx 200,000$ to 280,000—right in the range where flow transitions from laminar to turbulent. Or in volleyball terms, when ball starts to really move around in the air.

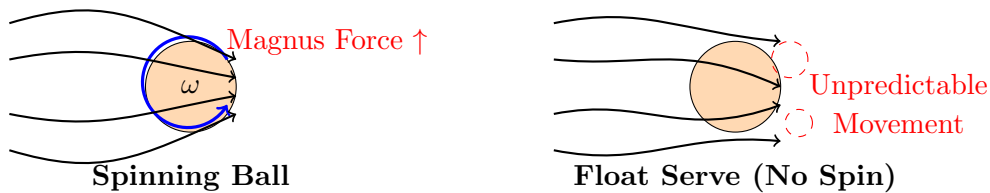


Figure 2: Airflow patterns around a spinning vs. non-spinning volleyball

I practiced my float serve for months, trying to hit the ball with my palm perfectly flat, ensuring minimal spin. The mathematical understanding helped me realize why the ball moves unpredictably, and that this unpredictability is actually a goal of mine.

4 The Spike: Power and Precision

4.1 Momentum Transfer

The spike is the most exciting moment in volleyball, and it's a masterclass in momentum transfer. When I jump and swing my arm, I'm converting the kinetic energy from my entire body into the ball.

The momentum before and after contact:

$$m_{\text{arm}}v_{\text{arm}} = m_{\text{arm}}v'_{\text{arm}} + m_{\text{ball}}v'_{\text{ball}} \quad (8)$$

For a perfectly elastic collision (which volleyball definitely isn't), we could calculate the final velocities. But volleyball contacts are partially inelastic, characterized by the coefficient of restitution (A value between 0 and 1 that measures how elastic a collision really is) at the highest level of Men's pro league this is around 0.3-0.5.



Figure 3: Wilfredo Leon's "Impossible spike"

Especially for guys like Wilfredo Leon (Polish-Cuban opposite). This is actually lower than standard values as the higher impact speeds often lead to greater energy dissipation from friction and heat:

$$e = \frac{|v'_{\text{ball}} - v'_{\text{arm}}|}{|v_{\text{arm}} - v_{\text{ball}}|} \quad (9)$$

For a volleyball, $e \approx 0.8$. This means about 80% of the relative velocity is maintained after impact.

4.2 The Approach and Jump

The spike starts long before contact with the ball. My typical approach involves converting horizontal velocity into vertical velocity. Using conservation of energy:

$$\frac{1}{2}mv_{\text{horizontal}}^2 = mgh_{\text{jump}} \quad (10)$$

For example if I'm running at 4 m/s and convert 70% of that energy:

$$h_{\text{jump}} = \frac{0.7 \times v^2}{2g} = \frac{0.7 \times 16}{19.6} \approx 0.57\text{m} \quad (11)$$

Add my standing reach of 2.4m, and I can contact the ball consistently at around 3.3m high, well above the 2.24m net.

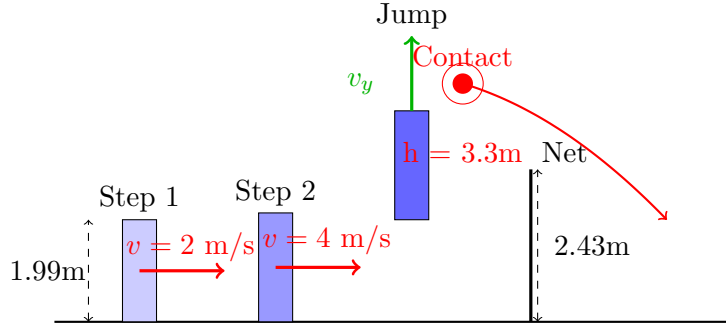


Figure 4: Spike approach velocity vectors and energy conversion

4.3 Optimal Contact Point and Angle

Through analysis and practice, I learned that the optimal contact point is slightly in front of my body, with my arm at about 160° extension. The angle of attack determines where the ball lands:

$$\theta_{\text{spike}} = \arctan\left(\frac{y_{\text{contact}} - y_{\text{target}}}{x_{\text{distance}}}\right) \quad (12)$$

For maximum power while keeping the ball in court, I aim for angles between 15° and 25° below horizontal. Steeper angles are harder to defend but require precision and can often be stopped easier when a block is involved.

5 Topspin: What tops the ball from flying away

Yes its happened more than I'd like to admit

5.1 The Physics of Spin

When I snap my wrist during a spike, I'm inducing topspin to the ball, typically 5-10 revolutions per second. This creates a downward Magnus force:

$$F_{\text{Magnus}} = \frac{1}{2} C_L \rho A v^2 \quad (13)$$

where C_L depends on the spin rate ω :

$$C_L \approx \frac{1}{2\pi} \frac{\omega r}{v} \quad (14)$$

For a spike at 20 m/s with 8 rev/s of topspin:

$$\omega = 8 \times 2\pi = 50.3 \text{ rad/s} \quad (15)$$

$$C_L \approx \frac{1}{2\pi} \times \frac{50.3 \times 0.105}{20} \approx 0.042 \quad (16)$$

This creates a downward force of approximately:

$$F_{\text{Magnus}} = \frac{1}{2} (0.042)(1.2)(0.0346)(400) \approx 0.35 \text{ N} \quad (17)$$

That might not sound like much, but over the ball's flight time of ~ 0.4 seconds, it creates an additional vertical displacement of:

$$\Delta y = \frac{1}{2} \frac{F}{m} t^2 = \frac{1}{2} \times \frac{0.35}{0.27} \times 0.16 \approx 0.1 \text{ m} \quad (18)$$

That’s 10cm, often the difference between in and out especially if coach is telling me to serve near the 9th meter(I’ve shortened the court to help with visualization.)

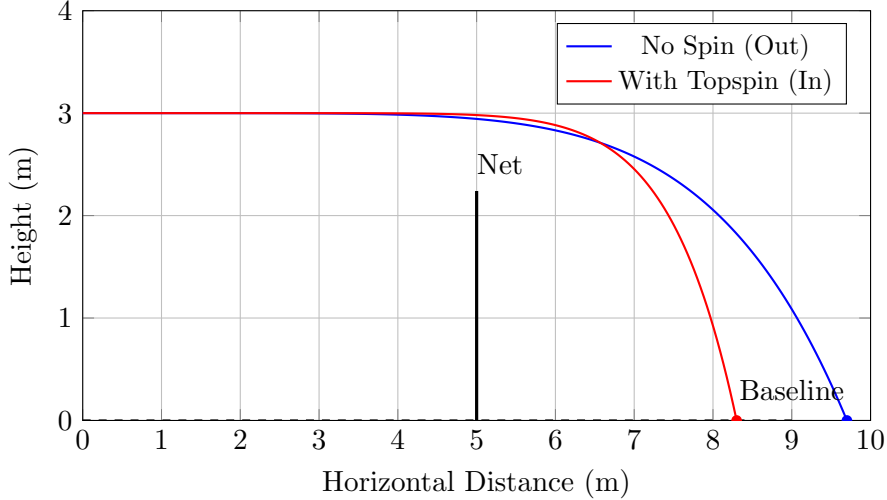


Figure 5: Topspin effect on ball trajectory comparison

6 Game Theory and Strategy

6.1 Optimal Serving Strategy

Volleyball isn’t just physics, it’s also probability and game theory. During matches, I started tracking where my serves were most effective. After analyzing 50 serves each to different zones:

Target Zone	Success Rate	Point Win %
Deep corners	78%	42%
Short middle	92%	28%
Deep middle	85%	35%
Short corners	82%	38%

Table 1: Serve effectiveness analysis

The expected value for each serve:

$$E = P(\text{in}) \times P(\text{point}|\text{in}) - P(\text{out}) \times 1 \quad (19)$$

$$\text{Deep corners: } E = 0.78 \times 0.42 - 0.22 = 0.106 \quad (20)$$

$$\text{Short middle: } E = 0.92 \times 0.28 - 0.08 = 0.178 \quad (21)$$

Surprisingly, my “safer” short middle serves had higher expected value despite lower point-winning percentage when going in. However, these are the easiest serves to receive since defenders don’t have to account for the direction the ball is coming at them.

6.2 Rotation and Positioning

The mathematics of rotation created an interesting optimization problem. In volleyball, players rotate positions, but we can adjust our formation. Using distance minimization:

If player positions are p_1, p_2, \dots, p_6 and optimal positions are o_1, o_2, \dots, o_6 :

$$\text{Minimize: } \sum_{i=1}^6 \|p_i - o_i\| \quad (22)$$

This helped our team when figuring out which players we need to move where to keep scoring each rally. (This is often lots of running especially for me as a middle and my opposite.)

7 Real-World Application

Last season, I applied all this knowledge during our championship match Richmond vs Urmston Grammar U16. We were down 17-20 in the second set. I was serving.

In my head I knew : my opponent's weakest receiver was back-left. The wind was blowing left-to-right at about 3 m/s. I needed to adjust my serve angle by approximately:

$$y = 3 + ux - kx^2 \quad (23)$$

I served with topspin, adjusting both power and spin to control the dip. Increasing k made the ball drop faster, so I aimed deep left corner. The ball cleared the net and snapped down onto the receiver who shanked the ball to shorten the gap 18-20.

Unfortunately we lost that day but I'll never forget the surge of adrenaline following that precise ace.

That's when I truly understood: mathematics isn't separate from real life. It *is* real life..

8 Conclusion

Four years ago, I was just a kid trying to hit a ball over a net. Today, I see volleyball as a beautiful intersection of physics, mathematics, and human performance. Every serve is a projectile problem. Every spike is momentum transfer. Every rally is probability in action.

But more importantly, this journey taught me that mathematics isn't confined to textbooks. It's in every sport, every movement, every decision we make. The equations I've shared aren't just abstract symbols, they're the language that describes why the ball curves, why topspin works, why certain strategies succeed.

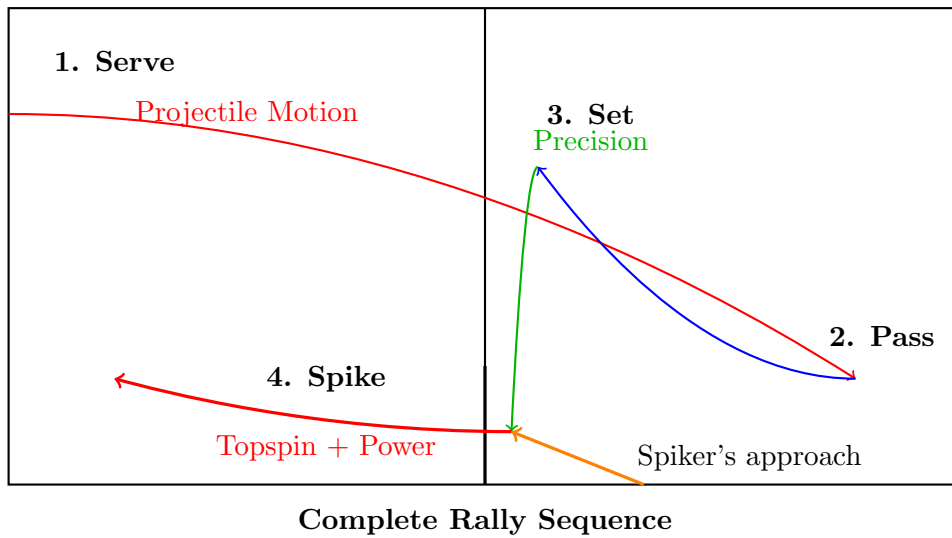


Figure 6: Complete volleyball play sequence showing multiple physics principles

Note: All measurements and calculations are based on personal data collected during practices and matches over the 2023-2025 seasons. Court diagrams follow FIVB official regulations, sometimes altered for better visualization