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Original article

BALLISTIC THROW IN BASKETBALL GAME

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Abstract*

Aim. From a physical point of view, in a basketball, when a player make a basketball throw, there are several factors that interfere that determine the ball's trajectory. The most important factors are: the weight of the ball, the speed at which the ball is launched by the player and the angle at which it is launched. There are also other factors that are not so important, such as air resistance, as well as the so-called rotational effect (Magnus effect), which is due to all the interaction with air, but it is of another nature , Being directly influenced by both the instantaneous speed of the ball and the angular rotation speed of the ball.

In this article we will treat the perfect throw to the basket in which the player attempts to execute a distance throw, outside the half-circle of 6.75 meters, so that the ball penetrates the basket without touching the ring.

Conclusions. Some models and assumptions allow us to calculate an approximate optimal angle, which would fall in the vicinity of 49°, for throwing speeds around a minimum of 8.2 m/s. When the throw angle drops noticeably below this value, the throw speed increases and the angle of entry in the basket decreases, lessening the chances of marking. On the other hand, when the throw angle increases noticeably, the throwing speed increases similarly, and the flight time is the same, which reduces the chances of the ball entering the basket. The more the player prints the ball at a higher angular speed, the more it has to print a lower initial speed, or to throw at higher angles (the input angles are even higher), both improving less chances of success.

Keywords: basketball, throw to the basket, ballistic, ideal trajectory

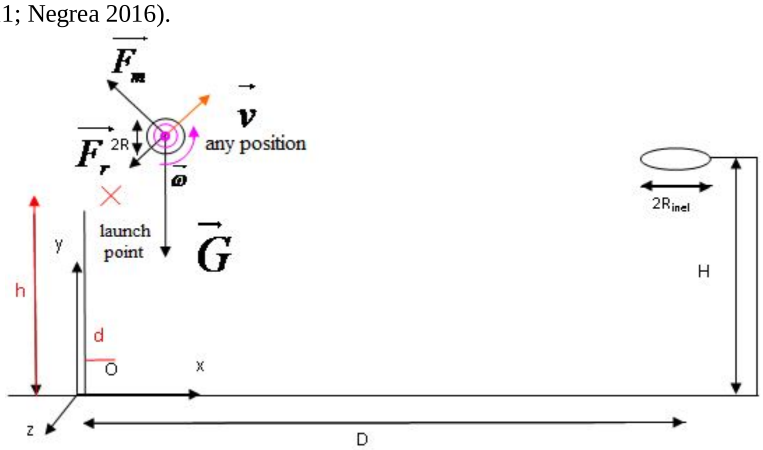
Introduction

Throwing in the basket is the technical element through which the goal of the game is achieved - the score. For this reason, it is one of the most attractive elements, demanding the highest accuracy, the correct acquisition of the movement and the increase of individual responsibility. (Predescu, Ghițescu, 2001)

In basketball, throwing a basket is an important moment depending on the effort of all teammates in the respective game phase (Negrea, 2011; Negrea 2016).

In basketball, basketball throws must not be accidental, made without any discernment, they must have a tactical justification of execution at the time of the game and be based on a well-trained technique. (Predescu, Grădinaru, 2005; Vasilescu, 1998)

In order to better understand how the factors that act during the throw-in to basketball basket, the following figure was formed, where the forces that act on a moving ball at any moment were represented.



$$\vec{G} = m \cdot \vec{g}$$
$$\vec{F_r} = -r \cdot \vec{v}$$
$$\vec{F_m} = \frac{\rho\pi R^3}{2} \vec{\omega} \times \vec{v}$$

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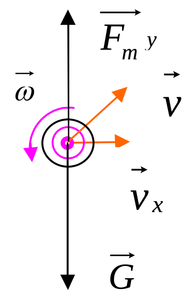
G = weight
F_r = force resistance
F_m = magnus force effect
g = acceleration due to gravity
v = speed
ω = angular velocity
ρ = air density
R = race
r = viscosity coefficient

We note that the force of resistance opposes the speed, always aiming to slow the ball, while the Magnus effect force is perpendicular to both the velocity vector and the velocity vector, the sense of force being given by the drill rule. In order to avoid the lateral deviation in the ball trajectory (after the Oz direction), the Magnus force must remain in the xOy plane, that is, the angular velocity vector is perpendicular to this plane. In other words, the ball must rotate either forward or back but not sideways. In the upper drawing, we notice that the ball is rotating backwards (the angular velocity vector exits the plane). It is natural for the ball to make such a spin, due to the movement the player's palm is doing before the throw. Thus, the Magnus force is oriented towards the outside of the trajectory, predominantly in the vertical direction, having the tendency to keep the ball in the air on a higher trajectory, which is advantageous, as we will see below. Also, by imparting the ball a controlled spin back, the player avoids giving the ball a spin that can divert the ball from the trajectory.

In a rigorous physical approach that follows the exact trajectory of the ball, the forces, accelerations and velocities on the Ox and Oy axes are first projected, and using the mechanics principle II along with the formulas above, we obtain a system of two differential equations . After solving these equations, the parametric equations x (t) and y (t) (where x and y are spatial coordinates and t is the time) result from exponential functions. The solution of the system of differential equations and the exact forms of the two parametric equations are quite elaborate and not very relevant to the present subject, they are not treated.

Instead, we can choose a simplified approach to the problem, which also gives us enough precision for this situation. Thus, we will neglect the strength of the air resistance, the coefficient of air viscosity "r" being quite small. Also, because in the course of the movement the velocity direction is predominantly horizontal and the Magnus force implicitly vertical, we can only consider the vertical component of it, which depends on the horizontal speed.

Thus, we only remain with forces acting in the vertical direction, ie the weight and vertical component of the Magnus force. By neglecting the forces on the horizontal axis (Ox), we neglect implicitly the acceleration in this direction, considering the constant horizontal speed, as well as the constant Magnus force that depends on it, constant.



$$\vec{G} = m \cdot \vec{g}$$

$$\overrightarrow{F_{my}} = \frac{\rho \pi R^3}{2} \vec{v}_x \times \vec{\omega}$$

In the simplified model above, using force expressions and the principle II of mechanics for the Ox and Oy axes, we obtain the following set of trajectory parametric equations (where m is the weight of the basketball, v_o the initial velocity of the ball and the throw angle, the other symbols having the already known meaning).

$$x(t) = d + v_0 \cdot \cos\alpha \cdot t$$

$$y(t) = h + v_0 \cdot \sin\alpha \cdot t + \frac{1}{2}\left(\frac{\rho \pi R^3}{2m} v_0 \cdot \omega \cdot \cos\alpha - g\right)t^2$$

A first observation would be that the trajectory of the ball depends on three initial parameters: the launching speed, the angular velocity ω and the throw angle α being determined uniquely by them, the rest being constant (ball mass, radius, throw height h and distance horizontally to the edge of the semicircle D).

The ball will penetrate into the basket at time t_f for which x (t_f) = d = 6,75 m and y (t_f) = H = 3,05 m, ie when the spatial coordinates of the ball are the same as the basket, as can be seen from the drawing . By eliminating the time t_f in the system of two equations represented by these conditions, we can deduce a law expressed by a function of the type $v_0(a)$, showing how the throwing angle varies according to the throw angle for the ball to penetrate into the basket. Since the angular velocity affects the least trajectory and the simplicity, we considered a single value of the angular velocity, which corresponds to a frequency. This angular velocity is within the range of 0-10 rad / s between which it can take values under a normal throw (http://www.ntu.edu.sg/home5/pg02259480/balltrajectory.pdf). Later, we will also address the case without spin, for which the angular velocity is. Thus, we have the system:

$$\begin{cases} x(t)=D; \\ y(t)=H; \end{cases} \Leftrightarrow \begin{cases} v\cdot\cos\alpha\cdot t-(D-d)=0; & \Rightarrow t=\dfrac{D-d}{v_0\cos\alpha}; \\ v_0\cdot\sin\alpha\cdot t+\dfrac{1}{2}\left(\dfrac{\rho\pi R^3}{2m}v_0\cdot\omega\cdot\cos\alpha-g\right)t^2-(H-h)=0; \end{cases} \Rightarrow$$

$$\Rightarrow \frac{\rho\pi R^3}{2m}\omega(D-d)^2 v_0\cos\alpha-g(D-d)^2+2(D-d)v_0^2\cos\alpha\sin\alpha-2(H-h)v_0^2\cos^2\alpha=0;$$

It is noted that after elimination of time a second degree equation is obtained in the v_o variable, which after a series of algebraic and trigonometric processing can be written more accessible as follows:

$$v_0^2\cdot[(D-d)\sin 2\alpha-(H-h)(1+\cos 2\alpha)]+v_0\cdot\frac{\rho\pi R^3}{2m}\omega(D-d)^2\cos\alpha-g(D-d)^2=0;$$

Applying the theory of the second degree equation, and choosing the positive solution, we get the following expression of the throwing speed according to the throw angle, for the spin case:

$$v_{0s}=\frac{-\dfrac{\rho\pi R^3}{2m}\omega(D-d)^2\cos\alpha+\sqrt{\left(\dfrac{\rho\pi R^3}{2m}\omega(D-d)^2\cos\alpha\right)^2+4g(D-d)^2[(D-d)\sin 2\alpha-(H-h)(1+\cos 2\alpha)]}}{2[(D-d)\sin 2\alpha-(H-h)(1+\cos 2\alpha)]}$$

Considering that we have a ball with a mass m = 0,6 kg, with a radius R = 0,12 m, released from a height h = 2,2 m and a horizontal distance from the semicircle edge d = 0,2 m, with the spin mentioned above, which must penetrate through the center of the ring at distance D = 6.75 m from the semicircle end and height H = 3.05 m from the ground, knowing that atmospheric air has a density ρ = 1.168 kg / m 3 and that gravity acceleration is g = 9.81 N / kg, we generated a graph based on the above equation, which shows for each throwing angle the initial velocity required for the ball to penetrate through the center of the ring (the generation was based on 90 points, one corresponding to each angle from 1 ° to 90 °, using the special program of origin 7). The graph can be found in Figure 2, in a limited form to explicitly show the area more interesting (very small or very large angles have been eliminated).

The time t needed for the ball to traverse the trajectory until it enters the basket can be found for each angle, based on its value and the value of the initial speed already calculated, according to the formula (used above in system processing): $t_{fs}=\dfrac{D-d}{v_{0_s}\cos\alpha}$ and is required to find the angle of entry of the ball into the basket according to the formula: $\beta_s=arctg\dfrac{[(g-\frac{\rho\pi R^3}{2m}\omega v_{0_s})t_{fs}-v_{0_s}\cos\alpha]}{v_{0_s}\cos\alpha}$

For both time t and angle, a series of discrete values, corresponding to the same throwing angles α from 1-90 degrees, were calculated. These values helped to plot a graph representing the angle of entry according to the angle of throw α, graphically represented in parallel with the one describing the initial velocity required by α for a more intuitive analysis. This graph is shown in Fig. 3, also shown in a limited form to correspond to the speed graph.

If the angular spin speed is 0, the formulas used are simplified. Thus, the velocity formula according to the input angle becomes: $v_0=\dfrac{(D-d)\sqrt{g}}{\sqrt{g[(D-d)\sin 2\alpha-(H-h)(1+\cos 2\alpha)]}}$, formula of the time needed for the trajectory: $t_f=\dfrac{D-d}{v_0\cos\alpha}$ and for the input angle: $\beta=arctg\dfrac{gt_f-v_0\cos\alpha}{v_0\cos\alpha}$.

These formulas also helped to generate graphs (a) and b (a) just as with spin spinning. These graphs were presented in parallel with the previous ones for the comparative study. The graph (a) can be seen in Fig. 2 along with the velocity graph for the spin case, identified with figure 2, and the graph β (α) is represented in Fig. 1. An additional graph of type tf (α) Fig. 4.

Both the graphs and the data on which they were drawn (which were only partially introduced in this paper) allow us to study the various possible trajectories for perfect throwing. In a simplified model, we can assume that the optimal trajectory is that trajectory for which at the given throwing angle, the initial velocity is minimal. This hypothesis is viable, because the faster the print speed is, the more the player puts out more effort during the throw, increasing the likelihood of mistakes.

In this approach, the optimal angle can easily be found using the graphs, or by invalidating

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the derived function $v_o(\alpha)$. By removing the derivative in the simple, spin-free case, the expression and the optimum angle defined above are obtained: $\alpha_0 = \frac{1}{2}[arctg\frac{(D-d)}{(H-h)} + \pi] \approx 49^o$

By analyzing the graphs, we can deduce the same value for the optimal angle in the case of 49º spinless. More interesting is that even in the case of spin, by analyzing the graphs and data, there is a similar value for the optimal angle of approximately 49º. It is noticeable, however, for the spin case that the required initial speed is slightly lower, which is advantageous for throwing as it will be immediately seen (this 49º angle has been marked on blue charts). Also regarding the initial throw speed, studies show that under normal discarding (http://www.ntu.edu.sg/home5/pg02259480/balltrajectory.pdf), this speed is preferably not higher than 10m /s, which would be required according to the graphs for very large throwing angles over 70°.

In addition to the throw rate, there are two other important factors that affect the probability of signing up for a basket throw. The first is the value of the angle under which the ball enters the basket, ie β, the probability of enrollment increasing proportionally to the value of the sinus at this angle. It can be seen from Figures 1 and 3 that this angle increases for both the spin and the non-spin case with the alpha throw angle, so from this point of view, the higher the throw angle, the higher the probability of registration. The throw angle can not increase very much, due to the second factor affecting the probability of enrollment, the time the ball stays in the air. The higher the flight time, the higher the chances for any mistakes made at the time of the throw to affect the trajectory of the ball. As the flight time graphs show that it increases with the throw angle for both spin and spin (in Figure 4 we have illustrated the graph tf (α) for the case without spin), we can say that this second factor affects the probability of enrolling against the first factor (makes the probability decrease with the increase of the throw angle).

Thus, large throwing angles are advantageous due to the large angles of entry into the basket, and disadvantageous due to the difficulty of controlling the trajectory, whereas for small angles things happen inversely. Taking into account both these two opposite factors, we are inclined to say that the optimal angle remains in the vicinity of the 49° angle identified by the above-mentioned method - a more accurate method of identifying this angle would imply certain probability calculations in relation to the three factors : throwing speed, input angle and flight time, but these exceed the area of interest of the subject.

It is worth mentioning that the angle of entry β can not be less than a certain value under which the ball could not pass through the ring. This minimum value is given by the formula $\beta_{\min} = \arcsin\frac{R_{ring}}{R} = 32°$ where R is the radius of the ball, and $R_{ring} = 0.225m$ is the radius of the basketball ring. This minimum input angle value implies a minimum throw angle of $\alpha_{\min} \approx 42°$ value valid for both the spin and the non-spin case and is deduced from the graphs represented in Figures 1 and 3. Both the β_{min} și α_{min} angles were marked in red in the corresponding graphs.

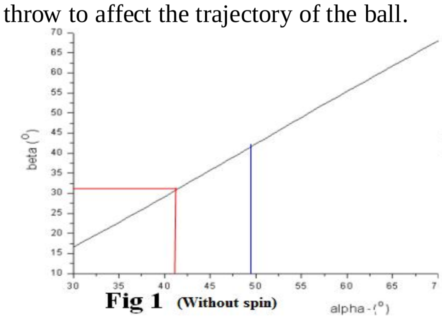


Fig 1 (Without spin)

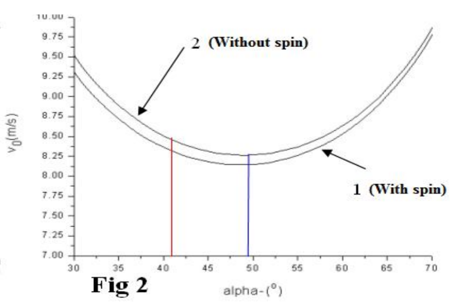


Fig 2

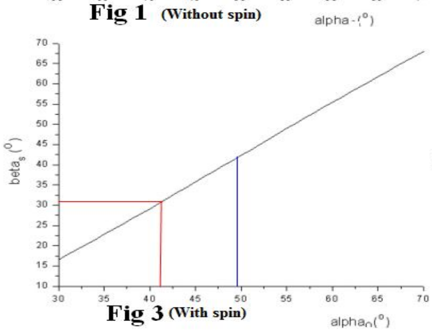


Fig 3 (With spin)

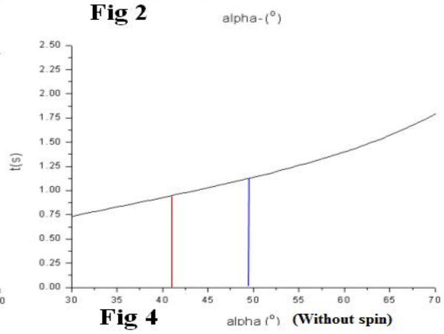


Fig 4 (Without spin)

After analyzing the above graphs the following main observations can be made (the majority already mentioned):

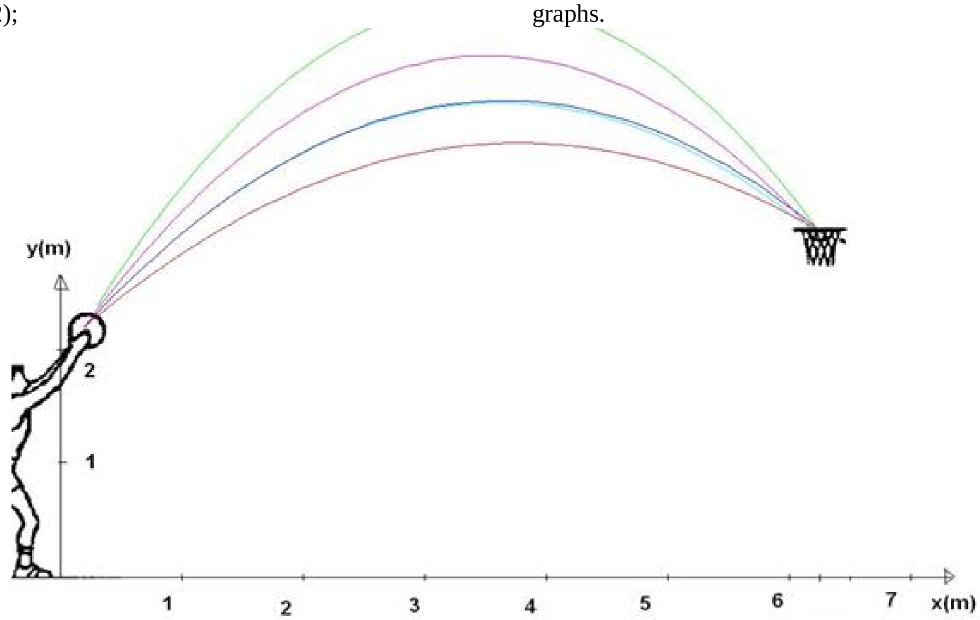
- the speed required to throw v_o, first decreases with increasing angle α, reaches a minimum (placed around 49º) after which it starts to grow, the evolution being similar for both the spin and the non-spin case (Fig. 2);

- when the angular velocity ω is higher, the required initial velocity v_o is smaller, for all angles α, (a phenomenon hardly perceptible, the differences consisting of several tenths of m / s for an increase of the angular velocity by almost 7 rad / s, Fig. 2);

- the value of the angle of entry of the ball into the basket b for a certain value α of the angle varies very little with the increase of the angular velocity ω, the two graphs for the case with spin and without spin being practically identical (Fig. 1 and 2);

- flight time tf increases with the throw angle α, as shown in the spinless graph of Fig. 4.

To better illustrate the physical phenomena presented above, I compiled the following diagram that contains some representative trajectories. Each trajectory is based on a data set of the type (v_o, ω, a) of those that were used to generate the previous graphs.



Trajectory 1: v0 = 8.40 m / s, ω = 0 rad / s, α = 42º - encompasses the minimum throw angle for which the ball can enter the basket, representative for small angles for which it is difficult to enroll due to the low angle of entry (tf = 0.96s, β = 32º);

Trajectory 2: v0 = 8.63 m / s, ω = 0 rad / s, α = 60º - trajectory representative for large angles, heavily controllable due to high flight time (tf = 1.40s, β = 55º);

Trajectory 3: v0 = 8.26 m / s, ω = 0 rad / s, α = 49 °; - Trajectory representative of optimal angles, characterized by minimum throw speeds, and equilibrium between input angle and flight time (tf = 1.11s, β = 41º);

Trajectory 4: v0 = 8.14 m / s, ω = 6.9 rad / s, α = 49º; - Trajectory representative of optimal spinning angles, with trajectory-like traits 3 except for lower throw speeds (tf = 1.13s, β = 41º);

Trajectory 5: v0 = 8.26 m / s, ω = 6.9 rad / s, α = 55º; - the trajectory chosen to have the same initial velocity as trajectory 3, but larger angles of entry and thrust due to spin (tf = 1.27s, β = 55º);

Shooting basketball and shot on goal in handball (Cazan, Georgescu, Rizescu, 2012) are very important moments of the game, the great responsibility that depends outcome of the game.

Synthesizing everything we have mentioned above, we can say that the perfect throw at the edge of the semicircle involves complex physical phenomena.

Conclusion

Some models and assumptions allow us to calculate an approximate optimal angle, which would fall in the vicinity of 49°, for throwing speeds around a minimum of 8.2 m / s. When the throw angle drops noticeably below this value, the throw speed increases and the angle of entry in the basket decreases, decreasing the chances of marking. On the other hand, when the throw angle increases noticeably, the throwing speed increases in a similar way, and the flying time is the same, which reduces the chances of the ball entering the basket.

The more the player prints the ball at a higher spin angular velocity, the more it has to print a lower initial velocity, or to throw at larger angles (the angles of entry are even greater), in both cases improving less chances of success. However, the angle or velocity differences are not very high, with the spin having an additional controlling role, the player achieving a balance between the spin, the initial speed and the throw angle, trying to maintain the optimal trajectories of the type in the last drawings with 3, 4 and 5. Balancing and compensating these determinant parameters for the ball trajectory becomes essential for the player, this being achieved by the last movement of the palm preceding the throw.

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