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Research on basketball shooting techniques best parameter based on numerical simulation and Matlab simulation

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ABSTRACT

There is an inseparable relationship between basketball techniques development and its theoretical research. The merits of shooting technique play an important role in deciding teams' victory. Basketball shooting technical process can be roughly divided into three stages as players throwing motions, basketball soaring process and basketball entering into the hoop. This paper using theorem of kinetic energy to analysis throwing motions and establish mathematic model, applying dynamics and fluid mechanics to analyze basketball off-hand flight process and build its mathematic model, utilizing extreme value of a function theory to analyze basketball hoop entering stage and establish the optimized mathematic planning model, then build the best throwing model with integration of 3stages optimized designing, finally make Matlab modeling simulation and data simulation to the whole process , get the best throwing distance of basketball is 4.6m, the best throwing angle is 62.75º, the best throwing speed is 7.92m/s when basketball not rotates.

Key words: Fluid mechanics, hollow constraints, Matlab track simulation, numerical simulation

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INTRODUCTION

In basketball match, make the hoop is players finally pursuit, therefore the shooting rate is the decisive factor to match to some extent. In order to make players find their own suitable shooting quantifications in training process, this paper makes research on basketball's sport trajectory and other dynamic parameters with the example of hollow shooting to explore best way of hollow shooting and enhance the prospects of success in basketball match through established models and data simulation as well as numerical simulation that mentioned in the paper.

For the studies on basketball shooting and sports condition of basketball out of hands, many people have made efforts, some domestic scholars has put forward their thoughts and theory that make a certain contribution to our country's basketball , among them, Chen Jian Utilize aerodynamics, sports biomechanics as well as statistics probability to analyze basketball rotations effect on shooting , shooting aims mark selections' diversity as well as its influence on shooting rate, get that ball's forward and backward rotation in shooting is up to shooting motions, from which forward rotation mainly used for low-handed shot in running, backward rotation mainly used for perimeter shot, the bigger ball rotation velocity is the high stability the ball would be, backward rotation increases ball's arc and improves shooting rate[1]; Duan Ran Establish physical model of players shooting through objects' movement law as well as mechanics principle, proved that some key angles in different position of field, ball's velocity as well as make ball backwards rotation play an important role in improving shooting rate when shooting[2]; Li Yu-Zhong Explore shooting problems with mechanics principal through analysis of basketball sports trajectory in shooting process, that provides theoretical evidences to improve shooting rate[3].

This paper makes an analysis of mutual effects between basketball and players, force conditions of basketball moved in the air after out of hands as well as hollow shooting requirements based on previous studies, explores models reliability as well as hollow shooting's best parameters through establishment of mathematic models as well as data simulation and numerical simulation.

BASKETBALL THROWING MODEL

Ball and hand interaction model:

When human hands make interaction with basketball, the greater the pressure between them, the stronger hands touch feeling would be, and hands possess stronger keep-ball ability at this time. It can be concluded that increase pressure between hands and ball in a certain range can achieve high quality ball control. In shooting process, wrist movements directly influences on ball's movements, requirement of wrist joint rotation angel range is normally [120 ° , 180 °] in this process. When starting shooting, pressures are gradually increasing that only slightly drops till wrist joint and finger joint fall backwards, one peak value would be appeared in the moment that two joints starts falling backwards according to action force's continuity that we call it as the first peak value. When hands form arrive at 2/3 positions, a wrist flexion process would turn up, followed by the rise of pressures between ball and hands till reach the second peak value, after reach the second peak value, human wrist advanced motion would be gradually reduced and pressures also reduced accordingly till basketball off-hands pressure drops to Zero [4]. During this process, pressure reducing would occurred follow by the appearance of first peak value, make human hands a weightlessness feeling at this time, when the second peak value less than the first ones or no big differences from first ones, human hands controlling to ball would be reduced that directly decides shooting rate. Therefore, shorten first peak value, increase the second value can avoid above bad effects; by players motion training, pressure diagram shows in Fig.1 $X_2O_2Y_2$ coordinate system can be got, four kinds of shooting pressure curve graphs have been respectively listed out in Fig.1, human hands effect on basketball dynamics can be calculated according to curve graph's shadow areas[5].

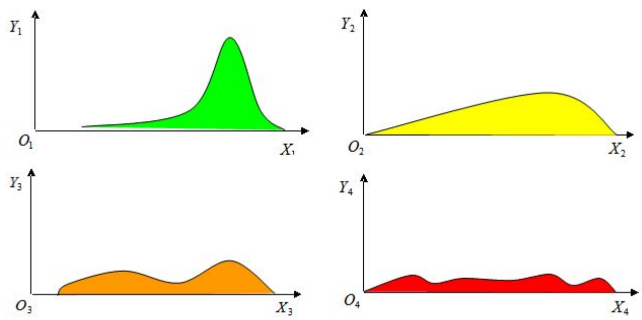

Fig.1: Shooting pressure curve graph

$X_1O_1Y_1$ coordinate system in Fig.1 stands for the most ideal pressure curve, $X_2O_2Y_2$ coordinate system stands for pressure curve after normal players make improvements, $X_3O_3Y_3$ coordinate system stands for normal players pressure curve, $X_4O_4Y_4$ coordinate system stands for relative worse pressure curve, from which Y axis represents pressure value, X axis represents pressure action distance, $X_i(i=1,2,3,4)$ represents hands displacement in the moment basketball taking off, shadow areas represent hands work on basketball pressure, according to theorem of kinetic energy get formula(1).

$$\begin{cases} \int_0^{X_1} Y_1(x)dx = \frac{1}{2}m\left(v_1^2 - v_0^2\right); \int_0^{X_2} Y_2(x)dx = \frac{1}{2}m\left(v_2^2 - v_0^2\right) \\ \int_0^{X_3} Y_3(x)dx = \frac{1}{2}m\left(v_3^2 - v_0^2\right); \int_0^{X_4} Y_4(x)dx = \frac{1}{2}m\left(v_4^2 - v_0^2\right) \end{cases} \tag{1}$$

m in formula(1) is basketball quality, while in hands pushing ball process, the gravitational potential energy of ball is thought to be no changes, therefore basketball bearing force approximately equal to pressure between hands and ball , so theorem of kinetic energy relation formula is true, v_0 represents center speed while basketball just contact with hands, $v_i(i=1,2,3,4)$ represents basketball end speed that also the initial speed of basketball off hands under the effects from the ideal pressure state、normal pressure state after improvements、 normal pressure state when improving as well as relative worse pressure state.

Hollow throwing model ignore of air drag:
After basketball taking off hands, if air drag ignored, basketball only bears gravity in soaring before getting into the hoop, its trajectory is a parabola, this chapter takes basketball throwing point as origins O, with vertical direction as Z axis, build 3D rectangular coordinate system, from which basket hoop center O'(L，0，h)'s projection in XOY plane is M'(L，0，0),basketball throwing elevation is α ,drift angle is β, ball center's initial speed is V_0, as Fig.2 shows.

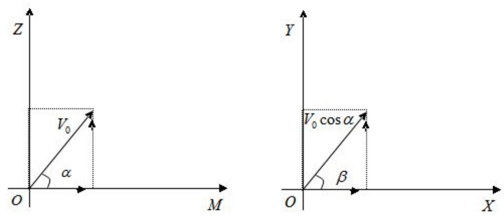

Fig.2: Decomposition of Basketball center initial speed

In Fig.2， vector $\overrightarrow{OM}$ represents throwing speed V_0 's project direction in XOY plane， α is throwing elevation(angle formed between speed V_0 and XOY plane)， β is drift angle that is the included angle between vector $\overrightarrow{OM}$ and X axis， it can be seen that basketball center trajectory's parameters equation just under gravity as formula(2) shows.

$$\begin{cases} X_0(t) = V_0 \cos\alpha \cos\beta * t; Y_0(t) = V_0 \cos\alpha \sin\beta * t \\ Z_0(t) = V_0 \sin\alpha * t - \frac{1}{2} g t^2 \end{cases} \tag{2}$$

$(X_0(t), Y_0(t), Z_0(t))$ in formula(2) represents basketball center's location coordinate followed by time changes.

According to sphere standard equation, equation of basketball surface's every point followed by time t changing as formula (3) shows.

$$\begin{cases} x(t) = r\cos\varphi\cos\theta + rX_0(t) \\ y(t) = r\cos\varphi\sin\theta + rY_0(t) \quad \varphi \in [-\frac{\pi}{2}, \frac{\pi}{2}], \theta \in [-\pi, \pi] \\ z(t) = r\sin\varphi + rZ_0(t) \end{cases} \tag{3}$$

$(x(t), y(t), z(t))$ in formula(3) represents any point of basketball surface's coordinate at t, r is radius of basketball， φ, θ mean parameters.

Basketball 's movement trajectory is first arrive at the top point of vertical direction, then drop into hoop from above down, time for vertical direction's top point can be got according to center's parameter trajectory equation, as formula(4) shows.

$$\frac{dZ_0(t)}{dt} = V_0 \sin\alpha - gt = 0 \Rightarrow$$
$$t = \frac{V_0 \sin\alpha}{g} \tag{4}$$

Then input formula (4) into formula (2) and formula (3), any point coordinate of basketball surface when it soared in the top can be got.

Basketball whether can hollow entering into basket when starts dropping after arrived at the top point is depend on hoop crossing as well as no touch between ball surface point and hoop ,hoop equation should be established as formula(5) shows.

$$\begin{cases} (x-L)^2 + y^2 = R^2 \\ z = h \end{cases} \tag{5}$$

R in formula(5) represents hoop's radius, simultaneous formula(3) and (5) can get hollow shot constraint equation as formula(6) shows.

$$\begin{cases} (x(t)-L)^2 + y^2(t) < R^2 \\ z(t) = h \end{cases} \quad t > \frac{V_0 \sin\alpha}{g} \tag{6}$$

Corresponding combinations of throwing speed V_0, elevation α, drift angle β can be got from formula(6).

Basketball best hollow throwing model with consideration of air drag:
No matter considering or ignoring air drag, basketball hollow entering into hoop's constraint condition would not be changed. That is when basketball arrived at top point then dropped into the hoop, sports top point should be higher than the height of hoop, when basketball center's vertical height arrived at hoop's height, and ball's edge no touched the hoop and ball itself dropped into the hoop. Then the constraint condition as formula (7) shows.

$$\begin{cases} (x(t)-L)^2 + y^2(t) < R^2 \\ z(t) = h \\ z(t)_{\max} > h \end{cases} \tag{7}$$

When basketball moved in the air, it would bear air's friction force and air pressure, such two forces is joint called as air drag. Experiment proved that air friction force is in direct proportion with ball's movement speed, the produce of air pressure is mainly air floating force and pressure that get in basketball flight and rotation process. In order to make detailed analysis of air drag conditions that basketball bearing, divided analysis process into 3 segments, from which the first segment is air friction force that is on the opposite direction of basketball speed ,its size is in direct proportion with speed, given proportion index as K, then friction force meet the condition in formula(8).

$$f(t) = -kv(t) \tag{8}$$

As formula(8) relation shows that three directions friction force component and speed component also meet the relation in formula(8).

Basketball's high speed backwards rotation can effectively overcome air friction, is helpful for ball to keep relative stability in the air, high speed backward rotation can enable basketball get a lift. According to fluid mechanics principle, ball that backwards rotated in top front side, due to air friction effects, sphere has unbalanced air flow through upper and lower part, upper part flow is less and quick while lower part is more and slow, therefore form into sphere air pressure be small in upper and big in lower, the difference of air pressure enable sphere produce a floating force in the air flight process, that is Magnus effect. Ball under the floating force deviates from the organized sports line from throwing speed and throwing angle, and forms into a special curve track, basketball flight heights is changed and meanwhile curve track's curvature increased by the force [6].

If both air density ρ and gravity accelerated speed g are constant basis， while changes of fluid height h to atmosphere can be ignored， according to formula(9)'s Bernoulli equation, it can be found that when v becomes bigger， p would be smaller，on the contrary p would be bigger.

$$p + \rho g h + \frac{1}{2}\rho v^2 = const \tag{9}$$

According to formula (9), airflow's sideways force F to basketball can be got as formula (10) shows.

$$F=\pi R^2\left(p_2-p_1\right)=\pi R^2\left[\left(h_1-h_2\right)\rho g+\left(v_2^2-v_1^2\right)\rho\right]=2\pi R^3\rho\left(g+2v\omega\right) \tag{10}$$

R in formula (10) represents basketball radius, h_2, h_1 are respectively the upper and lower edge point of basketball, v is basketball's vertical speed, ω is basketball rotation angular speed. Relation in formula (11) can be got.

$$F = M\frac{dv(t)}{dt} = 2\pi R^3\rho\left(g + 2v\omega\right) \tag{11}$$

RESULTS AND DISCUSSION

MATHEMATIC MODEL SIMULATION RESULTS ANALYSIS

Hollow throwing basketball trajectory simulation results analysis ignoring air drag:

Assign actual values to variables in previous model to make preparation for simulation. Given basketball radius $r = 0.123$ m, hoop radius as $R = 0.225$ m, vertical distance between throwing location and hoop $h = 1.25$ m, horizontal distance between throwing location and hoop gravity center $L = 4.60$ m, gravity accelerated speed $g = 9.8$ m/s2, initial sped $V_0 = 8$ m/s, input the above data into formula (6) can get equation as formula (12) shows:

$$\begin{cases} (0.123\cos\varphi\cos\theta + 0.123*8*\cos\alpha\cos\beta*t - 4.6)^2 \\ +(0.123\cos\varphi\sin\theta + 0.123*8*\cos\alpha\sin\beta*t)^2 < 0.225^2 \\ \sin\varphi + 8*\sin\alpha*t - 4.9t^2 = \dfrac{1.25}{0.123} \\ t > \dfrac{8*\sin\alpha}{9.8};\varphi\in\left(-\dfrac{\pi}{2},\dfrac{\pi}{2}\right);\theta\in(-\pi,\pi) \end{cases} \tag{12}$$

When drift angle $\beta = 0$, basketball throwing elevation $\alpha\in\left(61.32^o, 63.47^o\right)$, basketball trajectory's Matlab simulation curve as Fig.3 shows.

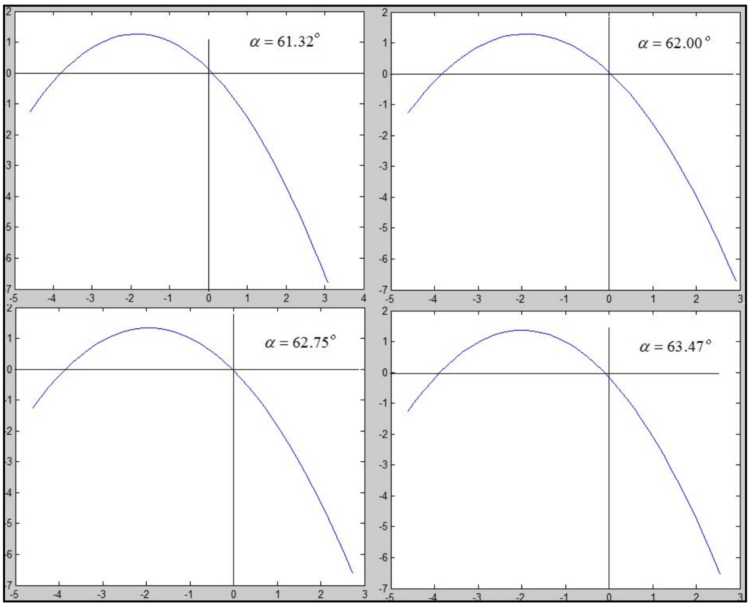

Fig.3: Basketball sports trajectory simulation ignoring air drag

Fig.3 shows basketball sports trajectory when elevation $\alpha = 61.32^o, 62.00^o, 62.75^o, 63.47^o$, area in origin (0,0) is the hoop center location, $y = 0$ intersection point between sports trajectory and y=0 line is the location that basketball center and hoop in the same horizontal line, basketball drops into hoop in the right intersecting point area.

Hollow throwing basketball numerical simulation with consideration of air drag:
In order to make basketball sports trajectory simulation with considering of air drag, especially given basketball radius $r = 0.123$ m， hoop radius $R = 0.225$ m， hoop's vertical height $h = 3.05$ m， gravity accelerated speed $g = 9.8$ m/s2， initial speed $V_0 \in (7.9, 14.1)$ m/s， basketball quality $m = 0.65$ kg， air density $\rho = 1.292 kg/m^3$， angular speed $\omega = 8\pi$ rad/s， input above data into formula (6) and formula (11) can get corresponding best shoot angle and basketball horizontal displacement in different throwing heights and speeds, Table 1 shows 11 kinds throwing speed's corresponding 3 kinds of throwing heights status.

Table 1: Best throwing angle and basketball horizontal displacement from different throwing speeds corresponded to different throwing heights

Basketball center throwing speed	Basketball center throwing heights					
	1.83 m		2.13 m		2.44 m	
	best angle	Horizontal displacement	best angle	Horizontal displacement	best angle	Horizontal displacement
7.92 m/s	38○	8.02m	37○	8.26m	37○	8.48 m
8.53 m/s	39○	9.07m	38○	9.31m	38○	9.55 m
9.14 m/s	40○	10.17m	39○	10.44m	39○	10.68 m
9.75 m/s	40○	11.38m	40○	11.63m	39○	11.88 m
10.36 m/s	41○	12.64m	40○	12.95m	40○	13.16 m
10.97 m/s	41○	13.98m	41○	14.24m	40○	14.50 m
11.58 m/s	42○	15.39m	41○	15.66m	41○	15.92 m
12.19 m/s	42○	16.87m	42○	17.15m	41○	17.41 m
12.80 m/s	42○	18.43m	42○	18.71m	41○	18.98 m
13.41 m/s	42○	20.07m	42○	20.34m	42○	20.62 m
14.02 m/s	43○	21.78m	42○	22.06m	42○	22.34 m

When horizontal distance of throwing location and hoop location L=4.57meter, select different throwing heights correspondingly quantities changes as Table 2 shows.

Table 2: Same shoot horizontal distance different throwing heights corresponding throwing speeds and angles

h/m	θ_{Om}	θ_{Om} (m/s)	$\Delta\Psi$	$\Delta v / V_{Om}$	$\Delta\theta_+ / \theta_{Om}$	$\Delta\theta_- / \theta_{Om}$
0.305	46.9	6.93	1.37	0.005	0.099	0.073
0.610	48.8	7.16	1.36	0.004	0.085	0.058
0.915	50.7	7.40	1.35	0.003	0.073	0.045
1.220	52.5	7.64	1.33	0.003	0.062	0.033

Note: h/m is the ratio between throwing heights to horizontal distance； θ_{Om} is the minimum speed angle； θ_{Om} (m/s) is the corresponding speed of minimum speed angle； $\Delta\Psi$ is the included angle that connection line from throwing location to hoop center location forms with horizontal plane

When throwing height $h = 0.61$ meter not changing and select different throwing distance, the condition as Table 3 shows.

Table 3: Get same throwing height different shooting distances corresponding throwing speeds and angle

h/m	θ_{Om}	θ_{Om} (m/s)	$\Delta\Psi$	$\Delta v / V_{Om}$	$\Delta\theta_+ / \theta_{Om}$	$\Delta\theta_- / \theta_{Om}$
3.05	50.7	6.04	2.02	0.005	0.094	0.052
4.57	48.8	7.16	1.36	0.004	0.085	0.058
6.10	47.9	8.13	1.03	0.004	0.078	0.058
7.62	47.3	9.00	0.82	0.003	0.072	0.056

Note: h/m is the ratio between throwing heights to horizontal distance； θ_{Om} is the minimum speed angle； θ_{Om} (m/s) is the corresponding speed of minimum speed angle； $\Delta\Psi$ is the included angle that connection line from throwing location to hoop center location forms with horizontal plane

CONCLUSION

This paper took basketball throwing and basketball sports trajectory as research objects, analyzed effects between basketball and human as well as dynamics principle that the two met, then made force analysis according to basketball off hands sports condition, got differential equations on the condition of air drag ignored and considered, got hollow shooting constraint conditions according to hoop, basketball and other mechanics parameters. Finally applied Matlab software fulfilled hollow shooting basketball movements' trajectory simulation images ignoring air drag, got basketball hollow shooting speed, displacement and other dynamics parameters changing features with considering of air drag through numerical solution.

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