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Research Article

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Table tennis defense influence factor dynamics analysis based on simulation model

Yingwei Fu

Institute of Physical Education, Sanya University, Sanya, China

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ABSTRACT

Make mechanics analysis on ball force status and movement states in table tennis process, and apply dynamic theory and fluid mechanic theory describe ball mechanic features. Analyze table tennis operation process as well as horizontal and vertical directions joint forces and angles, and get strength angle mathematical model. Make expansion on model, considering loop in table tennis, establish table tennis dynamics simulation model, and based on that add buoyancy force and additional mass force, establish improved table tennis simulation model, get conclusions that strong rotation speed loop can effective control flight distance and make high speed moving table tennis drops to opponent court.

Key words: Forehand smash, angular range, correlation analysis, whipping action, body center of gravity

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INTRODUCTION

Table tennis is hailed as China “national game”; it has the basis of broad masses in our country. Table tennis possesses high speed, strong rotation as well as multiple tactical changes feature, it has great difficulties [1-3]. Among them, loop is indispensible in training. Loop is a kind of strong attack force and high power attack technology. In loop running process, what cannot be ignored is Magnus effect that was found by German G. Magnus in 1852, its essence is a kind of viscosity effect that generated when rotation objects make movements in viscous fluid [4-6].

Table tennis emergence and development is closely related to mathematics, fluid mechanics, physics and other disciplines. Table tennis running mainly is serving and receiving; main concerns in serving and receiving process are peddler’s strength and serve angle problems [7-9]. This paper establishes table tennis strength angle model. Then based on that, considering loop force in running process, establish table tennis dynamics simulation model. Make improvement on model based on that, adding consideration of loop running process force, establish table tennis dynamics simulation improved model.

TABLE TENNIS STRENGTH ANGLE MATHEMATICAL MODEL

Table tennis development is closely related to mathematics, kinematics, mechanics and other disciplines, if properly apply mechanics, mathematics and other knowledge in table tennis technique research, it can change course with its own thought and make ball technique improving to some extent. And table tennis running mainly is serving and receiving, main concerns in serving and receiving process are strength and angle problems. In the following, it makes analysis of table tennis running process bearing horizontal and vertical directions strength and angle, establish table tennis strength angle mathematical model [10-12].

Table tennis horizontal force status analysis

Take right side rotation cross-court shot as an example to carry out analysis. In racket hitting process, racket vertical center line and table tennis rebound direction have a certain included angle. One paddler from them serves a right

rotation cross-court shot from point A; another paddler receives the server ball at point B and hits it to opponent court point C. If ignore table tennis rotation in the process, according to image principle, then table tennis running process hypothetical center line lies in the center of angle∠ABC that incident angle is equal to emergence angle, at this time α = β, as Figure1 shows.

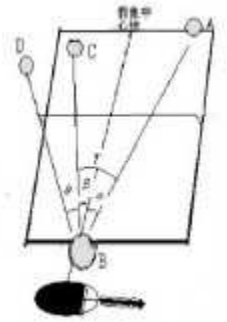

Figure 1: Table tennis running process figure

But considering practical status, paddler in table tennis hitting process, table tennis possesses it own rotation feature, therefore if continue to consider table tennis don't make rotation incident angle is the same as emergence angle, table tennis would deviate towards opponent court right side to a certain degree and arrive at Figure 1 point D. To let table tennis correct drop to point C, then it should let hypothetical center line left deviate to a certain angle, its angle is angle ∠CBD, and table tennis in running process should go through net and drop to opponent court range. To make such implementation, it should also adjust racket and table included angle as well as paddler rocket hitting strength.

In order to let table tennis drop into table tennis court one anticipated point at a certain speed and strength, establish table tennis strength angle mathematical model. Given table tennis weight as m_1, racket weight as m_2, racket surface rubber elastic coefficient as d_1, racket surface rubber friction coefficient as f_1, table tennis speed as v_1, table tennis racket speed as v_2.

Let horizontal direction C point achieving joint force as $F_{C-\textbf{Horizontal}}$, A direction table tennis generated reaction force as F_A. Table tennis rotation generated D direction friction force is F_D.Racket hits table tennis generated elastic force is F_M. Then joint force $F_{C-\textbf{Horizontal}}$ expression is as formula (1):

$$\sum F_{C-\textbf{Horizontal}} = \sum (F_A + F_D + F_M)$$
$$\sum_{t_0}^{t_1} F_{C-\textbf{Horizontal}} = \sum_{t_0}^{t_1} [F_A \cos\gamma + m_1 f_1 \frac{dwr}{dt} \cos\theta + d_1(m_1 + m_2)\frac{dv_1}{dt}]$$
$$F_{C-\textbf{Horizontal}} = F_A \cos\gamma + m_1 f_1 aw \cos\theta + d_1(m_1 + m_2)a \quad (1)$$

Table tennis vertical direction force status analysis

Let table tennis arrived at C point force to be $F_{C\text{-}Vertical}$, and then it has formula (2):

$$\sum F_{C\text{-}Vertical} = \sqrt{F_s^{\,2} + F_h^{\,2}}$$
$$F_s = d_1(m_1 + m_2)a \;;\; F_h = m_1 g \quad (2)$$

Racket speed is v_0, table tennis speed that leaves out of racket is v_x, table tennis touch racket time is Δt. Then accelerated speed is as formula (3), $F_{C\text{-}Vertical}$ transformation is as formula (4):

$$a = \frac{v_x - v_0}{t - t_0} = \frac{v}{t} = \frac{dv}{dt}$$
$$F_s = d_1(m_1 + m_2)\frac{dv}{dt} \quad (3)$$

$$F_{c\text{-}Vertical} = \sqrt{[d_1(m_1 + m_2)\frac{dv}{dt}]^2 + (m_1 g)^2} \quad (4)$$

Table tennis horizontal direction and vertical direction joint force status analysis

According to parallelogram law, solve horizontal direction and vertical direction joint force F, its size as formula (5):

$$F^2 = F_{C-\mathbf{Horizontal}}{}^2 + F_{C\text{-}Vertical}{}^2$$
$$F = \sqrt{F_{C-\mathbf{Horizontal}}{}^2 + F_{C\text{-}Vertical}{}^2}$$
$$F = \sqrt{[F_A \cos\gamma + m_1 f_1 aw\cos\theta + d_1(m_1 + m_2)a]^2 + [d_1(m_1 + m_2)\frac{dv}{dt}]^2 + (m_1 g)^2} \quad (5)$$

When hits table tennis flying in A direction from paddler, if according to image theory let incident angle to be equal to emergence angle, then table tennis would drop to D point; to let table tennis drop to specified C point, it should let hypothetical center line left deviate to a certain angle, θ = ∠C B D.

Convert formula $F_{C-\mathbf{Horizontal}}$, it can get formula (6):

$$F_{C-\mathbf{Horizontal}} = F_A \cos\gamma + m_1 f_1 aw\cos\theta + d_1(m_1 + m_2)a$$
$$\cos\theta = \frac{F_{C-\mathbf{Horizontal}} - F_A \cos\gamma - d_1(m_1 + m_2)a}{m_1 f_1 aw} \quad (6)$$

So that further solves table tennis running strength and angle mathematical model formula (7):

$$F = \sqrt{[F_A \cos\gamma + m_1 f_1 aw\cos\theta + d_1(m_1 + m_2)a]^2 + [d_1(m_1 + m_2)\frac{dv}{dt}]^2 + (m_1 g)^2}$$
$$\cos\theta = \frac{F_{C-\mathbf{Horizontal}} - F_A \cos\gamma - d_1(m_1 + m_2)a}{m_1 f_1 aw} \quad (7)$$

TABLE TENNIS MOVEMENT PROCESS MODEL EXPANSION IN ACTUAL COMPETITION AND TRAINING

Combine aerodynamics and classical mechanics theory, analyze and set table tennis dynamics simulation model that including gravity, air resistance, Magnus force, on the basis of the model with consideration of buoyancy force and additional mass force, it establishes improved table tennis dynamics simulation model [8, 9].

Table tennis dynamics simulation model

The model main concerns table tennis mainly suffers gravity, air resistance, Magnus force in movement process, as Figure 2 shows.

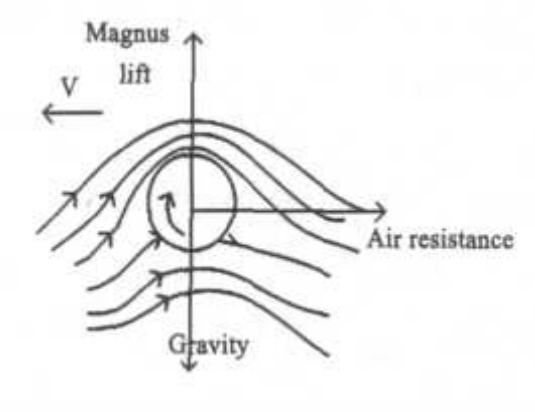

Figure 2: Table tennis force analysis figure

Gravity is G, direction is downward. Air resistance direction is opposite to table tennis movement direction, its size is up to air density ρ、windward area A、line speed v and resistance coefficient C_d etc., according to fluid dynamics formula, calculate formula (8) as following:

$$F_d = \frac{1}{2} C_d \rho A v^2 \tag{8}$$

Among them, resistance coefficient C_d is got by wind tunnel experiment. This paper assumes resistance coefficient is only up to table tennis translational speed and angular speed, adopt following method to calculate formula (9):

$$C_d = 0.508 + \left(\frac{1}{22.053 + 4.196\left(\frac{v}{\omega}\right)^{5/2}}\right)^{2/5} \tag{9}$$

When table tennis rotates in air, it will be affected by Magnus force. When a rotational object rotation angular speed vector mismatches to object flight speed vector, it will generate a horizontal force in vertical direction of a plane that composed of rotation angular speed vector and translational speed vector. Under the horizontal force function, object flight trajectory would appear deflection. The phenomenon that objects flight trajectory appears deflection under the horizontal force function is called Magnus effect, the horizontal force is Magnus force. It can be used to explain ball type movements (table tennis, tennis, football and so on) loop generation.

Set flight speed vector as v, angular speed vector as ω, then Magnus force is F_m, vertical to v and ω, computational formula is as following formula (10):

$$\vec{F}_m = \frac{1}{2} C_m \rho A |\vec{v}|^2 \frac{\vec{\omega}}{|\vec{\omega}|} \times \frac{\vec{v}}{|\vec{v}|} \tag{10}$$

Among them, C_m is Magnus force lift force coefficient that got by experiment measuring. C_m Compares to C_d, it is quite small. Assume that C_m is only up to linear speed v and angular speed ω, adopt below method to calculate formula (11):

$$C_m = \frac{1}{2.022 + 0.981\frac{v}{\omega}} \tag{11}$$

Make force analysis of it as Figure 3shows: Set table tennis translational speed as v, air resistance as F_d, Magnus

force as F_m, gravity as G, translational speed v and XOY plane included angle as α, translational speed vector in XOY plane projection and x axis included angle as φ, Magnus force and XOY plane included angle as β, Magnus force projection in XOY plane and x axis included angle θ, according to Newton the second law F = ma list out following equation, get table tennis dynamics simulation model formula:

$$\begin{bmatrix} \cos\alpha\cos\varphi & \cos\beta\cos\theta & 0 \\ \cos\alpha\sin\varphi & \cos\beta\sin\theta & 0 \\ \sin\alpha & \sin\beta & 1 \end{bmatrix} \begin{bmatrix} F_d \\ F_m \\ G \end{bmatrix} = m\left[\frac{dv_x}{dt}, \frac{dv_y}{dt}, \frac{dv_z}{dt}\right]^T \tag{12}$$

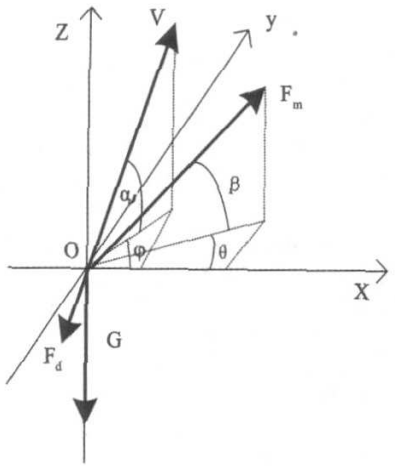

Figure 3: Table tennis force analysis

Table tennis dynamics simulation model improvement

This model on the basis of table tennis dynamics simulation model adds buoyancy force and additional mass force to make improvement on table tennis dynamics simulation model, analyze different rotation speeds influences on loop.

Rotational table tennis in running process mainly suffers gravity, buoyancy force, additional mass force, air resistance and Magnus force effects as Figure 4 shows. Among them, gravity is vertical and downward, buoyancy force is vertical and upward, air resistance direction is opposite to table tennis movement direction.

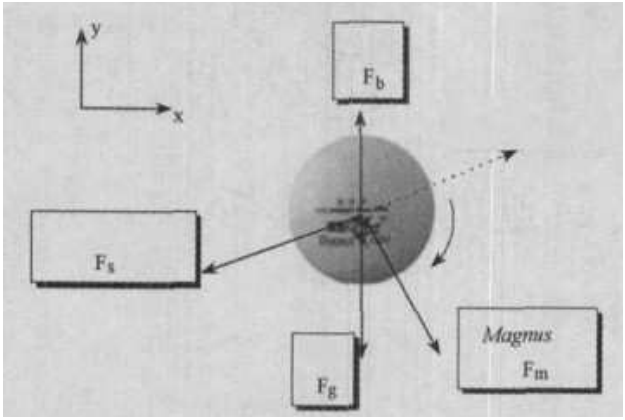

Figure 4: Table tennis force analysis figure

Gravity F_g expression as following formula (13):

$$F_g = mg = \frac{1}{6}\pi\rho_d d^3 g \tag{13}$$

From which, ρ_d is table tennis density, d is table tennis diameter, table tennis diameter is 40 mm, mass is around 2.7 g.

Buoyancy force F_b is equal to table tennis sphere arranged same volume air mass force, its computation formula (14) is:

$$F_b = m_a g = \frac{1}{6}\pi\rho_a d^3 g \tag{14}$$

From them, ρ_a is air density?

For induction magnetic field generated additional mass force, its size is as formula (15):

$$F_{m'} = \frac{1}{12}\pi\rho_a d^3 \frac{dv}{dt} = \frac{1}{2} m_a \frac{dv}{dt} \tag{15}$$

$\frac{1}{2} m_a$ Is always recording as m', is called additional mass. Additional mass force can be ignored when table tennis speed hasn't greatly changed.

When table tennis takes movements, it always suffers a resistance that on the opposite direction of movement in the range of high Reynolds number area, its computational formula (16) is:

$$F_D = C_D \frac{1}{8}\pi\rho_a d^2 V^2 \tag{16}$$

From them, C_D is resistance coefficient, V is absolute speed. Research found that it can express C_D according to different Reynolds number ranges with three groups of different formulas as formula (17)-(19):

$$C_D = \frac{24}{R_a} \quad R_a < 1 \tag{17}$$

$$C_D = \frac{24}{R_a}(1 + \frac{R_a^{2/3}}{6}) \quad 1 < R_a < 1000 \tag{18}$$

$$C_D \approx 0.44 \quad (1000 < R_a < 2\times 10^5) \tag{19}$$

Among them, R_a is Reynolds number? For Magnus effect, its dominant mechanisms are:

1) Dissymmetry displacement thickness;
2) Dissymmetry centrifugal force;
3) Dissymmetry wall friction stress;
4) Dissymmetry transition;
5) Dissymmetry separation and body vortices;
6) Dissymmetry secondary flow.

For sphere, Magnus force can be expressed by following formula (20):

$$F_M = \frac{1}{8}\pi\rho_a d^3 V\omega \tag{20}$$

Among them, ω is rotational speed? According to Newton the second law, it can establish rotational table tennis horizontal and vertical dynamics equations:
Horizontal formula (21):

$$(m+m')\frac{d^2x}{dt^2} = -\frac{1}{2}C_d\rho v\frac{dx}{dt}\pi(\frac{d}{2})^2 + \frac{1}{8}\pi\rho d^3\frac{dy}{dt}\omega \tag{21}$$

Vertical formula (22):

$$(m+m')\frac{d^2y}{dt^2} = -F_g + F_b - \frac{1}{2}C_d\rho v\frac{dy}{dt}\pi(\frac{d}{2})^2 - \frac{1}{8}\pi\rho d^3\frac{dx}{dt}\omega \tag{22}$$

Among them, t is time. Calculation adopted border and initial condition as table 1 shows, table tennis initial speed is 11m/s, angle is 15°; sphere is the standard 40mm large ball, 2.7g weight; ambient air is in normal pressure and temperature; rotational speeds are calculated with different levels as 0、40、80、120、160r/s.

Table 1: Model initial parameters

Parameters	Values
Initial translational speed	V=11m/s, $\phi = 15^\circ$
Initial rotational speed	0、40、80、120、160r/s
Sphere	m=2.7g, d=40mm
Initial position	x=0, y=0
Environment	T=20 $^\circ C$, P=1atm

Through above research, it can get that table tennis movement is a gravity, buoyancy force, additional mass force, resistance and Magnus force combined action process. Rotational speed has great influences on table tennis flight trajectory, Figure 5 draws table tennis movement trajectory at different rotational speeds. From Figure5, it is clear that table tennis serves at same initial speed in the same position, different rotational speeds would let their movement trajectory different. Finally it concludes that strong rotational speed loop can control flight distance in some extent and make table tennis drop into opponent court in high speed movement.

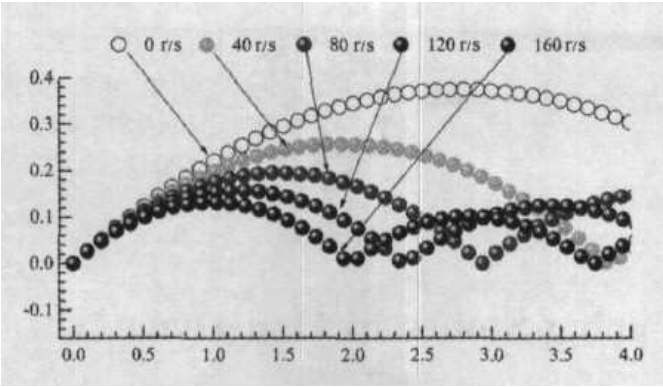

Figure 5: Same start point different rotational speeds table tennis rotation trajectory

CONCLUSION

Through researching on table tennis running process mathematical model, considering table tennis serve and receive process, carried out analysis of table tennis running process suffered horizontal direction force, vertical direction force as well as horizontal and vertical directions joint force, established joint force angle mathematical mode. The model considered running trajectory when table tennis didn't rotate, and base on that it combined with practice, considering table tennis rotation running trajectory, it was relative intuitive. After that, it expanded model, considered from table tennis running process suffered gravity, air resistance, Magnus force, established table tennis dynamics simulation model by force analysis and applying fluid mechanics knowledge. Then on that basis, it considered buoyancy force and additional mass force, established table tennis dynamics simulation improved model, the improved model researched loop running trajectory and speed, analyzed different rotational speed influences on

loop, and got the conclusion that strong rotational speed loop can control table tennis flight distance in some extent and make table tennis drop into opponent court in high speed movement.

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