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Magnus force model applied research in table tennis flying process trajectory

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ABSTRACT

Table tennis movement process is very complicated; it includes space movement and its own rotational movement. In table tennis self-rotating movement, it has non -rotating and rotating two forms; table tennis space movement trajectory is correlated to racket and table tennis collision moment friction force, push force as well as momentum and others, and it can be divided into horizontal movement trajectory and vertical movement trajectory. Table tennis in flying process mainly suffers vertical and downwards gravity, vertical and upwards buoyancy force, air resistance that in the opposite direction of movement, as well as self-rotating produced Magnus force, its movement trajectory is arc. The paper puts emphasis discussion on table tennis flying process self-rotating produce Magnus force that is table tennis running process's every kind of force status; finally it defines table tennis first trajectory equation by force analysis.

KEYWORDS

Table tennis;
Movement trajectory;
Air resistance;
Magnus force.

INTRODUCTION

In China best known as "national ball" table tennis has broadly mass base, except for that, to larger competitive sports, table tennis still is a kind of big difficulty sport, it is because that the sport needs flexible cooperation from consciousness, motion as well as fast pace and other each aspect. Table tennis, since introduced to China in 1904, it is rapidly well received by mass. But Chinese table tennis haven't got significant development until new China was founded; since 1960s Chinese table tennis players have gradually taken world table tennis game most even whole champions. Therefore, researching on table tennis is very important. In table tennis game, spin ball is a technique that game players most utilize, which is also the key to loop. Table tennis in rotation process, it includes complex aerodynamic principle, and it will suffer all kinds of force effects in the whole flying process and is a kind of continuous process, therefore it is very necessary to table tennis research.

For table tennis trajectory researches, lots of people have made efforts and achieved results, which provides favorable conditions for scholars from all sectors of society making research on it, and provides impetus for table tennis development. For example: Wang Ming-Yu and others made research on robot table tennis playing track trajectory prediction problems; in the paper, it pointed out trajectory prediction problems were timer shaft trajectory tracking further extension, trajectory

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prediction crucial trajectory prediction algorithm on robot hitting success rate was mainly divided into two types of methods based on kinematic model and table tennis robot based on experience method, in hitting process we should first judge and predict incoming ball trajectory so that could provide sufficient time for sports controlling system to drive arms hitting ball; In 1997, Japanese Osaka University professor Wiki Fumio cooperated with Shanghai Jiao Tong University Rui Qin and others theoretically researching table tennis simulation algorithm and trajectory prediction, they proposed a kind of linear regression algorithm adopting partial weight; Han Yi-Zhong and others researched loop spinning intensity important influences on table tennis flying trajectory, fast loop arc was flat, flying speed was fast, and high loop arc was high, flying speed was slow; in fact, if it could sufficiently utilize rotational power, applying loop technique could control drop point and dropping time; if it could make quantitative analysis of spinning speed influences on drop point, dropping time and flying speed, it can create high-level hitting technique.

Further understand loop technique has an important significance, especially that present international table tennis rules are constant changing, and then it more needs scientific theoretical method to guide new rules' loop technique application and development. The paper mainly researches loop trajectory changes causes by mechanical analysis, it provides theoretical basis for table tennis players' improving their techniques.

TABLE TENNIS FLYING PROCESS FORCE ANALYSIS AND TRAJECTORY EQUATION DEFINING

Table tennis flying process force analysis

When a rotating object rotational angular speed direction misaligns to object flying speed direction, it will produce a horizontal force in rotational angular speed direction and translational speed direction composed plane's vertical direction. Under the horizontal force effects, object flying trajectory occurs deflection phenomenon is called Magnus effect. The reason that rotating object can generate force in horizontal direction by physical perspective analysis is due to object rotation can drive surrounding fluid rotation, let object one side fluid speed increase and another side fluid speed decrease. The horizontal force is Magnus force[1].

Loop pressure difference that produced because of rotation is called lift force F_L that is Magnus force[2]. It is related to sphere movement speed and rotational frequency, its expression is as following:

$$\mathbf{F_L = C_L \rho D^3 f v} \quad (1)$$

Table tennis suffered air resistance size is related to maximum cross section area as well as suffered wind speed. As following Figure 1 show, assume it has not yet arrived at table tennis airflow is called "state 1", and it regarded airflow that has already arrived at table tennis as "state 2", $v_2 = 0$, by Bernoulli principle, it can get:

$$\mathbf{P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2} \quad (2)$$

It is unit volume airflow pressure energy, from which $v_1 = v$, $v_2 = 0$, then $P_1 - P_2 = \frac{1}{2}\rho v^2$, if it is thought that table tennis other side suffered pressure is equal to pressure in front state 1 P_1, multiply by table tennis maximum cross section area A, it gets resistance F_d [3]:

$$\mathbf{F_d = (P_2 - P_1)A = \frac{1}{2}\rho A v^2} \quad (3)$$

But consider other factors influences, it introduces resistance coefficient C_d, it can get final formula:

$$\mathbf{F_d = \frac{1}{2} C_d \rho A v^2} \quad (4)$$

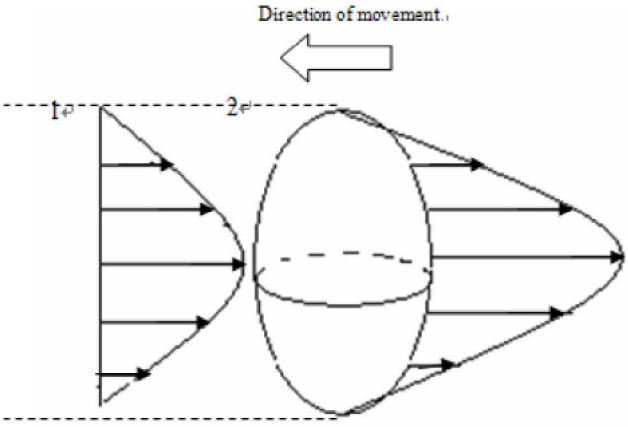

Figure 1: Table tennis suffered air resistance

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Ignoring gravity effects orbit analysis, table tennis force schematic diagram is as following Figure 2 show.

Therefore it can get dynamic equation as following:

$$\mathbf{m\frac{dv}{dt}=\frac{1}{2}C_d\rho Av^2} \quad (5)$$

$$\mathbf{m\frac{v^2}{R}=C_L\rho D^3fv} \quad (6)$$

Deform and sort out formula, use diameter D expressing maximum cross section area A, and let $v = v(t)$, it can get curvature radius formula:

$$\mathbf{R = R(t) = \frac{m}{C_L\rho D^3 f}v(t)} \quad (7)$$

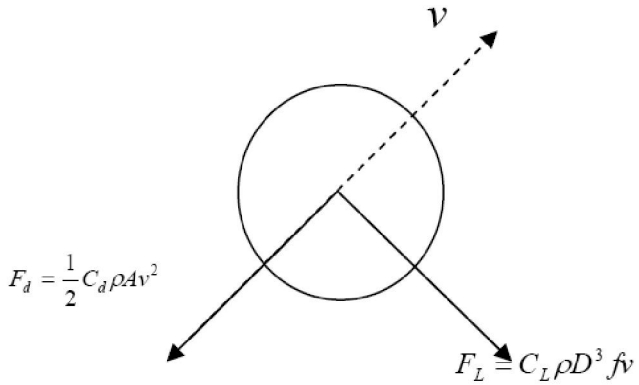

Figure 2: Ignoring gravity effect orbit analysis

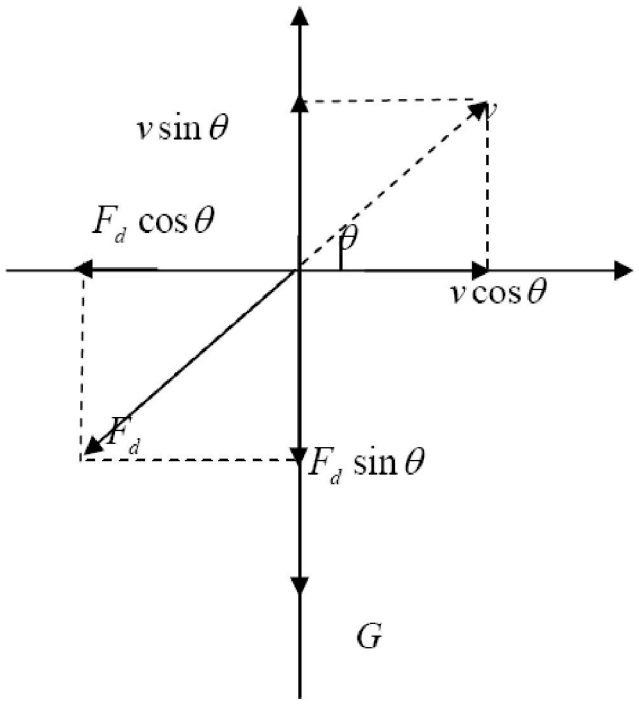

Figure 3 : Table tennis force status orthogonal decomposition

Table tennis force decomposition

Make orthogonal decomposition of table tennis force status, it gets as following Figure 3.

Vertical direction force analysis

Vertical direction initial speed is $v\sin\theta$, suffered upwards direction compound force $F_d\sin\theta + G$, ground distance S_0.

When table tennis makes upwards movement:

$$v_{vertical} = v\sin\theta - a_{vertical}t,$$

$$a_{vertical} = \frac{F_d\sin\theta + G}{m}$$

It can get lift time: $t_1 = \frac{v\sin\theta\cdot m}{F_d\sin\theta + G}$

Lift displacement: $S_1 = \frac{1}{2}\frac{v^2\sin\theta^2 m}{F_d\sin\theta + G}$

Vertical direction total displacement:

$$S = S_0 + S_1$$

When table tennis moves upwards:

$$S = \frac{1}{2}at_2$$

It can get falling time:

$$t_2 = \sqrt{\frac{2mS_0}{F_d\sin\theta + G} + \frac{v^2\sin\theta^2 m^2}{(F_d\sin\theta + G)^2}}$$

That table tennis movement time in the air is:

$$\mathbf{t = t_1 + t_2} \quad (8)$$

Horizontal direction force analysis

When table tennis makes horizontal movements:

$$v_{horizontal} = v\cos\theta - a_{horizontal}t,$$

$$a_{horizontal} = \frac{F_d\cos\theta}{m}, t = t_1 + t_2$$

Horizontal movement displacement:

$$\mathbf{S_{horizontal} = v\cos\theta\cdot t - \frac{1}{2}\frac{F_d\cos\theta}{m}\cdot t^2} \quad (9)$$

Table tennis trajectory equation defining

Table tennis flying first trajectory refers to one move-

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ment process that table tennis flies away from racket to just contact table. Table tennis in flying process mainly suffers vertical downwards gravity, vertical upwards buoyancy force, and air resistance that opposite to movement direction. Generally, table tennis in flying process, it will rotate with axis, therefore, it should also consider Magnus force.

Assume that table tennis only moves in the plane xoy. Ball speed is v and horizontal line form θ angle, rotation speed is $\gamma\left(\gamma=\frac{\omega}{2\pi}\right)$, rotation axis and vertical plane.

Buoyancy force $F_{buoyancy}=\frac{1}{6}\rho g\pi D^3$, resistance $F_d=\frac{1}{2}C_d\rho A v^2$, $A=\frac{\pi D^2}{4}$ is table tennis cross section area. Magnus force $\mathbf{F_d = C_L\rho D^3 fv}$ [4]

According to Figure 4, it carries out force analysis, decomposes force along x and y direction, and then it can list out kinematic equation.

$$\mathbf{m\frac{d^2x}{dt^2}=C_L\rho D^3 fv\sin\theta+\frac{1}{2}C_d\rho Av^2\cos\theta} \quad \textbf{(10)}$$

$$\mathbf{m\frac{d^2y}{dt^2}=mg-\frac{1}{6}\rho g\pi D^3+C_L\rho D^3\gamma v\cos\theta+\frac{1}{2}C_d\rho Av^2\sin\theta} \quad \textbf{(11)}$$

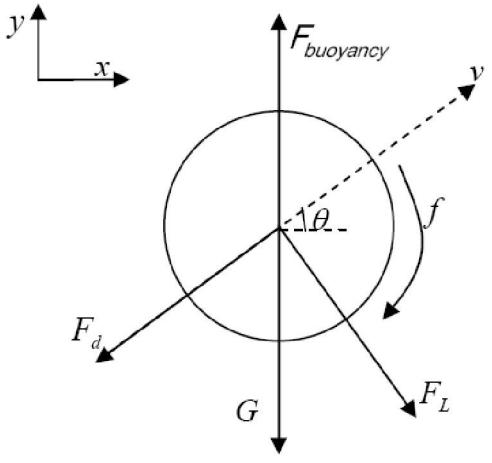

Figure 4 : First trajectory force analysis figure

CONCLUSIONS

Through researching, it finds out gravity and others effect on table tennis first trajectory, and the research is also fit for football and other balls movements. Table tennis trajectory in flying process is related to initial state and flying process force. Table tennis during collision process with racket, it gets initial state, and then it starts space movement. Table tennis in flying process, it mainly suffers vertical downwards gravity, vertical upwards buoyancy force, air resistance in the opposite direction of movement, as well as self-rotating generated Magnus force, its movement trajectory is arc.

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