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Table tennis flight simulation techniques to theoretical model analytic demonstration

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ABSTRACT

With flight simulation techniques application in military aircraft, table tennis theoretical model verification also gradually starts to use flight simulation techniques. The paper firstly states flight simulation techniques concept, introduces flight simulation system basic composition structure. Secondly, divide table tennis flight into three phases that include racket and table tennis contacting process, table tennis air flight process, table tennis and table collision process, and from physics special knowledge perspective, targeted at every phase, it makes force analysis. Finally, analyze digital simulation, real object simulation and semi-real object simulation such three technical ways most suitable analytic table tennis theoretical model simulation technique from analysis of speed, analysis of cost, and analysis of convenience and simulation efficiency four aspects. Research result shows, semi-real object simulation is the simulation technique that most suitable to analyze table tennis theoretical model.

KEYWORDS

Simulation technique; Table tennis; Theoretical model; Analytic hierarchy process; Mathematical model.

INTRODUCTION

With rapidly development of information technology, simulation technique gradually has more applications. Up to now, simulation technique has already been widely used in national defense construction, education research, sports technological research and so on multiple aspects. In table tennis sports model establishment, simulation technique is used to verify model rationality.

In 2008, Jiang Fu-Gao and others in the article "Table tennis flight kinematics model establishment and simulation", targeted at flying table tennis, they made force analysis, analysis showed that table tennis during flight process, except for suffering gravity and air resistance influences, it would also suffer Magnus force effects that caused by rotation. On this basis, authors established space coordinate system that was fit for solving. Regarded Newton's second law as theoretical basis, they established mathematical model. By *Matlab* software, they made simulation processing with table tennis flight trajectory, and then verified model's rationality. In 2010, Zhao Lei in the article "Table tennis flight process mechanical analysis and *Matlab* simulation", made analysis of the whole process that racket stroke ball and ball flied out of table after colliding with table, established models from mechanical perspective, and by *Matlab* simulation technique, they verified established model.

In 2012, Guo Hai-Jun in the article " Table tennis robot dynamical analysis and joint simulation research", targeted at robot table tennis mechanical system and control system aspects, went deeper into theoretical analysis, and took real stroking environment as examples, made table tennis simulation analysis. For table tennis dynamical analysis, it mainly constructed dynamical equation through Lagrange method, according to five orders polynomial, planned stroking trajectory, and utilized dynamical simulation to define model rationality. According to table tennis movements, ball and racket as well as table collision, established stroking model, utilized predicted table tennis movement trajectory, planned stroking paths, and reflected robot stroking scenes by simulation technique. With regard to robot control system, utilized speed, current and position tricyclic servomechanism theory, constructed control system's mathematical model, and defined systematic parameters by simulation techniques so as to implement systematic accurate controlling.

In 2012, Zou Jun-Hua in the article "Table tennis sports technology learning research in the view of information technology", highlighted that in information technological era, people should fuse information technology into practical teaching life so as to promote education quality. Table tennis was Chinese national ball, but its sports techniques were not easy to grasp. Author research pointed out that in table tennis daily training, information technological application mainly contained curriculum management system, online learning environment, experts animation examples and video feedback such four aspects. Curriculum management system generated certain impacts on table tennis trainers by techniques, social environment and attitudes and emotions as well as other factors. Online learning environment affected learners training initiative by situation, environment and other factors. In experts' animation examples, they were implemented by decomposing motions, slow motions and playing frame by frame.

The paper takes analytic hierarchy process as theoretical basis, makes comprehensive evaluation on flight simulation techniques that are suitable to table tennis theoretical analysis from multiple aspects.

FLIGHT SIMULATION TECHNIQUE

Flight simulation takes flying machine as research objects, establishes mathematical model according to kinematics, dynamics and flight control theory as well as others multiple aspects professional knowledge, and bases on the model to make experimental research. By far, flight simulation has been widely applied in aviation flying aspect; it provides essential help to flying machine development, production and utilization.

According to simulation type and simulation implementation paths differences, it can divide flight simulation into digital simulation, real object simulation and semi-real object simulation three types. Digital simulation refers to utilize computer programs to implement pure digital calculation; it mainly is applied in flying machine performance estimation and analysis. Real object simulation and semi-real object simulation mainly rely on computer, on the basis of adding peripheral equipment; create flying conditions that get closer to practice.

Flight simulator includes air simulation and ground simulation, but narrow flight simulator generally refers to group devices that can timely reflect approximately real flying state in the ground. It is composed of computer, sound, vision and other systems; its structure schematic graph is as Figure 1 shows.

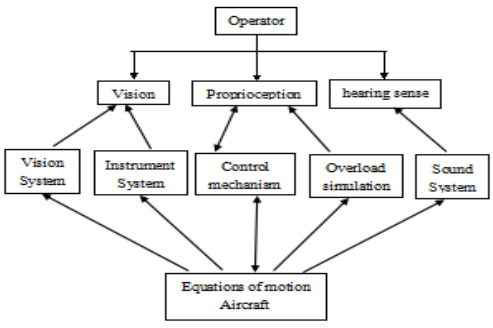

Figure 1 : Schematic diagram of the flight simulator

From Figure 1, it is clear that control mechanism has bidirectional effects no matter for operators' proprioception or flying machine sports equation set.

THEORETICAL MODEL

For table tennis model, firstly it should go ahead with force analysis, divide table tennis flight into three phases, the first phase is racket and table tennis contacting process, the second phase is table tennis air flight process, and the third phase is table tennis and table collision process.

Racket contacts with table tennis

Racket and table tennis contacting process suffer two forces effects, one is racket to ball impact force F, second is racket and ball friction force f, in the process, it ignores gravity influence, and regard both table tennis initial speed and initial angular speed as 0 as Figure 2 shows.

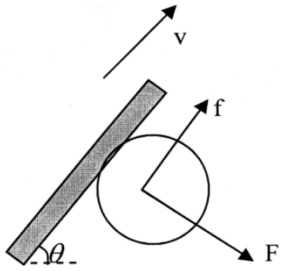

Figure 2 : The first stage of stress analysis diagram

In Figure 2, it shows racket and table included angle is θ. Assume racket and table tennis contacting time is t_0, athlete swinging racket speed is v, table tennis mass is m, table tennis diameter is D。

In the time frame of t_0, two forces impulses:

Friction force f : $I_f = \int_0^{t_0} f dt$

Impact force F : $I_F = \int_0^{t_0} F dt$

And meanwhile, friction force f generates moment of force $\frac{D}{2} f$, impulsive moment is $\frac{D}{2}\int_0^{t_0} f dt$.

Table tennis rotational inertia: $I_c = \frac{2}{3} m r^2$, end speed that along F direction is V_F, end speed that along f direction is V_f, end angular speed is ω. On the basis of momentum theorem and angular momentum theorem, it can get:

$$I_F = m v_F \quad \textbf{(1)}$$

$$I_f = m v_f \quad \textbf{(2)}$$

$$\frac{D}{2} I_f = I_c \omega \quad \textbf{(3)}$$

Decompose table tennis speed in horizontal direction v_x and vertical direction v_y, it can get table tennis out of racket instant speed (It is table tennis initial speed).

$$v_x = v_F \sin\theta + v_f \cos\theta = \frac{I_F}{m}\sin\theta + \frac{I_f}{m}\cos\theta \quad \textbf{(4)}$$

$$v_y = v_f \sin\theta - v_F \cos\theta = \frac{I_f}{m}\sin\theta - \frac{I_F}{m}\cos\theta \quad \textbf{(5)}$$

Table tennis flying process

Table tennis in flying process mainly suffers three forces acting, one is self gravity, two is air buoyancy force, and third is air resistance in falling process. In addition, table tennis in flight process, it may occur to rotate, therefore it also should consider the existing of Magnus force, and force analysis schematic graph is as Figure 3 shows.

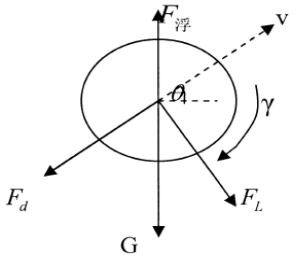

Figure 3 : The second phase of stress analysis diagram

Firstly regard table tennis moves in the two-dimensional plane xoy , from Figure 3, it is clear that table tennis speed and horizontal included angle is θ, rotation speed is γ , when table tennis rotates, rotational axis is vertical to xoy . Gravity G 、buoyancy force F_{buoyancy} 、resistance F_d and Magnus force F_l solving process is as following:

$G = mg$ (In general, $g = 9.8m/s^2$) **(6)**

$$F_{\text{buoyancy}} = \frac{1}{6}\rho g \pi D^3 \quad \textbf{(7)}$$

$F_d = \frac{1}{2} C_d \rho A v^2$ (C_d is one table tennis resistance coefficient) **(8)**

$F_l = C_L \rho D^3 \gamma v^2$ (C_L is lift force coefficient) **(9)**

Make decomposition on Figure 3 forces, it can get equation as following:

$$\begin{cases} m\dfrac{d^2x}{dt^2} = C_L \rho D^3 fv \sin\theta + \dfrac{1}{2} C_d \rho A v^2 \cos\theta \\ m\dfrac{d^2y}{dt^2} = mg - \dfrac{1}{6}\rho g \pi D^3 \\ + C_L \rho D^3 \gamma v \cos\theta + \dfrac{1}{2} C_d \rho A v^2 \sin\theta \end{cases} \quad \textbf{(10)}$$

Table tennis and table collision process

In table tennis and table collision process, table tennis suffered forces include two parts, one part is table to table tennis elastic force, the other is table to table tennis friction force, force status is as Figure 4 shows.

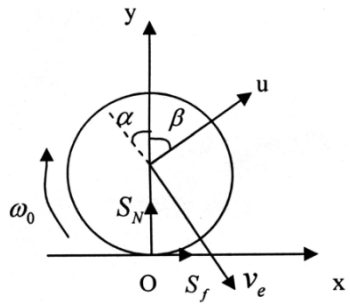

Figure 4 : The third stage of stress analysis diagram

Assume speed that table tennis oblique collides the table is v_e, from Figure 4, it is clear that decompose it along horizontal direction and vertical direction, it can get $v_e x$ and $v_e y$, speed that table tennis rebounds from the table is u, decompose it along x and y direction into u_x and u_y, restitution coefficient is e, friction coefficient is μ. Analysis method and 3.2 process method are basically the same. Result is as following:

When table tennis and table contact, its speed is consistent to assumed direction, it can get:

$$\begin{cases} u_x = v_{ex} + \mu v_{ey}(e+1) \\ u_y = -ev_{ey} \\ \gamma' = \gamma - \dfrac{3\mu}{4\pi r} v_{ey}(e+1) \end{cases} \quad \textbf{(11)}$$

When table tennis and table contact, its speed is opposite to assumed direction, it can get:

$$\begin{cases} u_x = v_{ex} - \mu v_{ey}(e+1) \\ u_y = -ev_{ey} \\ \gamma' = \gamma + \dfrac{3\mu}{4\pi r} v_{ey}(e+1) \end{cases} \quad \textbf{(12)}$$

OPTIMAL SIMULATION TECHNIQUE ON THEORETICAL MODEL ANALYSIS

For table tennis theoretical model analysis flight simulation technique, it includes digital simulation, real object simulation and semi-real object simulation three types. In practical analysis process, flight simulation techniques selection is a relative complicate problem. The model establishment takes analytic hierarchy process as theoretical basis, and carries out from analysis of speed, analysis of cost, and analysis of convenience and simulation efficiency four aspects. By lots of questionnaire survey, and process with investigation data, it can get the four aspects importance as TABLE 1 shows.

TABLE 1 : Importance ranking

	Percentage (%)	Ranking
Simulation efficiency	50	1
Analysis of convenience	42.3	2
Analysis of speed	40.1	3
Analysis of cost	19.4	4

AHP principles

AHP can solve relative tedious and vague problems' decision-making problems. Use the method to construct model, it roughly needs four steps :

- Hierarchical structure establishment;
- Construct every layer that fully used in judgment matrix;
- Hierarchical single arrangement and consistency test;
- Hierarchical total arrangement and consistency test

In the following, it respectively states each step detailed process.

AHP solved problems are required to be hierarchic, orderly and logic. Only then it can construct hierarchical scheme. Let tedious problems' elements to form into multiple hierarchies according to its attributes, membership and its relations. Last hierarchical element plays a dominate role in next hierarchical relative elements. In general, these hierarchies can be divided into 3 types:

(1) Top layer: Only one element in this hierarchy, it normally is final target of analytic problems. The layer is also called target hierarchy.

(2) Middle hierarchy: In this hierarchy, it includes intermediate links that get involved to fulfill targets, which can be composed of some hierarchies that include multiple and multilayer criterions that required to consider. It can also be called criterion hierarchy.

(3) The bottom hierarchy: This hierarchy includes optional each method and way to fulfill targets. It can also be called measure hierarchy or scheme hierarchy.

Hierarchy numbers in hierarchical structure have something to do with problem's complicated degree as well as analysis detailed requirements, normally the hierarchy numbers are not limited, each element in every hierarchy governs less than 9 elements. Hierarchical structure is as Figure 5.

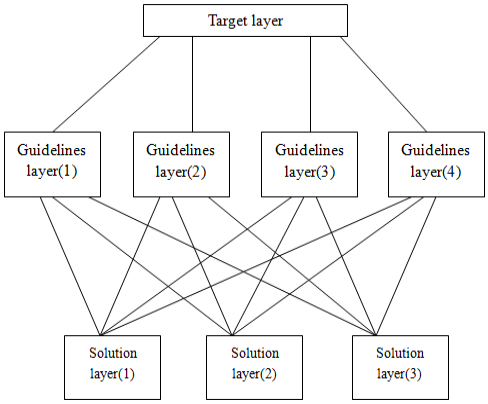

Figure 5 : Hierarchical structure chart

In Figure 5, layer 1 is target layer that is the purpose which is required to finally fulfill for researching problems, layer 2 is criterion layer that is the medium process that researching problems go through,layer 3 is scheme layer that is each kind of referencing schemes. In general, the first layer is one factor, the second and third layer has multiple factors and quantity is not fixed.

Judgment matrix construction

Each layer structure can show factors relationships, but in middle layer, each factor occupied proportion in target evaluation basically will not be fully the same, in the heart of evaluators, each factor has certain proportions.

When define each factor proportion that is to compare n pieces of factors $X=\{x_1,\cdots,x_n\}$ to factor Z impacts. $Saaty$ and others proposed to carry out paired comparison among factors, and constructed comparison matrix method. That is to say, it selects two factors x_i and x_j every time,uses a_{ij} to express x_i and x_j to Z impacts ratios, all comparison is using matrix $A=(a_{ij})_{n\times n}$ to express, A has become judgment matrix between $Z-X$. From matrix, it is clear that if x_i and x_j to Z impact ratio is a_{ij} ,then x_j and x_i to Z impact ratio is $a_{ji}=\frac{1}{a_{ij}}$.

According to linear algebra theoretical knowledge, if matrix $A=(a_{ij})_{n\times n}$ meets $a_{ij}>0$ and $a_{ji}=\frac{1}{a_{ij}}(i,j=1,2,\cdots,n)$,then matrix A is positive reciprocal matrix.

a_{ij} value determination can according to scale table, contents are as following TABLE 2.

TABLE 2 : Scale table

Scale	Definition
1	Indicates two factors have equal importance by comparing
3	Indicates the former is slightly more important than the later by comparing two factors
5	Indicates the former is obviously more important than the later by comparing two factors
7	Indicates the former is intensely more important than the later by comparing two factors
9	Indicates the former is extremely more important than the later by comparing two factors
2, 4, 6, 8	Indicates middle level of above judgment
Reciprocal	If i to j is a_{ij}, then j to i is $\frac{1}{a_{ij}}$

Result analysis

In the model, target layer is optimal simulation technique, criterion layer is analysis of speed, analysis of cost, and analysis of convenience and simulation efficiency; Scheme layer is digital simulation, real object simulation and semi-real object simulation. Target layer paired comparison matrix is as TABLE 3 shows.

TABLE 3 : Target layer paired comparison matrix

A	B_1	B_2	B_3	B_4
B_1	1	3	4	7
B_2	1/3	1	2	5
B_3	1/4	1/2	1	4
B_4	1/7	1/2	1/4	1

For judgment matrix concrete construction, it will not further discuss. Use *Matlab* software program to solve, it can get result as TABLE 4.

TABLE 4 : Result analysis

Criterion		Analysis of speed	Analysis of cost	Analysis of convenience	Simulation efficiency	Total arrangement weight
Criterion layer weight		0.0961	0.0332	0.0331	0.0554	
Scheme layer single arrangement	Semi-real object simulation	0.4846	0.2585	0.2583	0.2792	0.3943
	Real object simulation	0.3505	0.6372	0.1047	0.0718	0.3055
	Digital simulation	0.1646	0.1048	0.6370	0.6492	0.3054

From TABLE 4, it is clear that semi-real object simulation weight is the highest. It indicates that semi-real object simulation is most suitable to analyze and verify table tennis theoretical model.

CONCLUSION

Flight simulation technique fuses simulation theory, computer science and aeronautics and astronautics as well as others multiple disciplines theoretical knowledge. Flight simulation technique applies in sports research is an important sign of simulation technique further development. The paper applies analytic hierarchy process in researching simulation types that fit for table tennis theoretical model verification, applies mathematical theories into practical research aspect, which shows in practical problems researches, select semi-real object simulation theory as verifying table tennis theoretical model's rationality to certain extent.

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