ISSN 1746-7659, England, UK
Journal of Information and Computing Science
Vol. 14, No. 3, 2019, *pp*.227-240

The Design and Implementation of Simulation System about Interior Ballistics of Gas-ejection

Xuefeng Zhang, Shimin Guan*, Yuezhong Chu, Yaling Tang

Anhui University of Technology, Anhui Maanshang 24300,China
(Received April 01 2019, accepted June 07 2019)

Abstract. In view of the numerical calculation of zero-dimensional interior ballistics is not efficient for catapult interior ballistic engineers and it is difficult to simulate the flow field in the two-dimensional interior ballistic numerical simulation, combining with computer simulation technology, we build a gas-ejection interior ballistic simulation platform according to the idea of system structure. In this platform, the numerical simulation of gas-ejection interior trajectory is carried out from zero-dimensional and two-dimensional interior trajectory mathematical model. The simulation of interior ballistic flow field is accomplished by fluid mechanics software, and output the images of the interior trajectory characteristic parameter curve and temperature, velocity and pressure field. To help engineers to study the impact of structure parameters, material parameters and environmental coefficients on missile ejection. Through the use of military unit testing, the platform has been validated.

Keywords: interior trajectory, zero-dimensional, two-dimensional, numerical simulation

1. Introduction

A missile that strikes a hostile target at a predetermined heading is called an ejection missile[1],[2][7]. Ballistic missiles are divided into strategic and tactical ballistic missiles, solid propellants and liquid propellant ballistic missiles, intercontinental, long-range, medium-range and short-range ballistic missiles according to different classification methods. Catapult missile launch is an external force to the missile fired from the launcher tube, the missile reached a certain height and then fired the engine's. For the study of gas-ejection trajectory, the main methods currently used are theoretical analysis, numerical simulation and experimental study. The theoretical analysis is the zero-dimensional interior ballistic mathematical simulation described in this paper, but the pure mathematical calculation lacks certain supportiveness and can't describe the details of gas flow field in gas-ejection trajectory. Of course, experimental research is the most effective and realistic research method. It requires constant adjustment of gunpowder parameters, functional parameters, etc. to conduct a number of live-fire launches in order to determine the approximate relevant parameters so as to formulate a relatively optimized launch plan, however, the disadvantage is that it consumes a lot of manpower and resources and is less efficient, so it isn't a realistic method. The United States has always been in a monopoly position in the production of catapults. Catapults loaded on aircraft carriers such as France and Brazil are also equipped by the introduction of U.S. technology[3],[5][8]. Based on the current catapults performance bulky, heavy weight, low energy utilization and other defects, on the basis of fully understanding the launching principle and structure of catapult, it is very important to design and analyze the parameters of catapult[9]. Due to the inability to pass large amounts of experiments in China at present, it is an effective measure to study the relevant characteristics of catapults in practical application by using numerical simulation.

A lot of work has been done in numerical simulation of catapult interior trajectory in China, such as Aerospace Institute in Northwestern Polytechnical University, Nanjing University of Science and Technology, Zhengzhou Institute of Mechanical and Electrical Engineering and so on, however, the realization of the gas-ejection trajectory simulation system is quite scarce. Taking the self-projectile catapult as an example, Tan Dacheng built a two-dimensional interior ballistic model of the launcher tube and calculated the interior ballistic performance. Comparing the two-dimensional model and the zero-dimensional model, the results showed that there was little difference between the two models[10]. In terms of the amount of calculation and calculation speed, the zero-dimensional model has a small calculation amount, a fast calculation speed, a large amount of calculation and a long time-consuming in the two-dimensional model. WeiHua Hui, etc. based on the mass conservation, conservation of energy, equations of motion, equation of state and considered various resistance who belongs to the Key Laboratory of Thermal Structure and Internal Flow Field of Northwestern

Polytechnical University, and they constructed the interior ballistic equations[5].At the same time, the interior ballistic simulation system of the projectile surface separation gas- ejection was established.

In this paper, the gas catapult is the research object. In order to study the characteristics of the interior trajectory during the ejection of the projectile missile, such as the pressure of the high pressure chamber, the pressure of the ejector, the temperature of the ejector, etc. Based on the zero-dimensional and two-dimensional interior ballistic mathematical model, we combined the gas-ejection interior ballistic numerical simulation with the computer simulation technology, using the C # language to develop the visual interface. By changing the relevant parameters of the high-pressure chamber and the launcher tube, it can output pressure curve of the high-pressure chamber, the launcher tube temperature’s curve etc. The simulation results of the two-dimensional and two-dimensional interior ballistic models were compared with the experimental results to verify the practicality of the gas-ejection interior ballistic simulation platform. The simulation results are real enough to predict and evaluate the accuracy of the missile's interior ballistic, and it has a certain guiding significance for the interior ballistic design. Finally, it will provide decision support for the typical missile launching system plan.

2. Overall design of system

The gas-ejection interior ballistic simulation system provides a development environment for missile launch designers, which is a good interactive, open and extendible environment. Designers are able to use visual interface to set up the interior ballistic parameters of zero-dimensional mathematical models and build the meshes and initial boundary of two-dimensional interior ballistic. The designers conduct theoretical calculations and simulation evaluations of interior ballistic characteristics by this system.

This system consists of two modules that are theoretical calculations and simulation evaluations about interior ballistic. Besides, the theoretical calculation contains two independent parts, which are the classic and the extrapolation interior ballistic model calculation[11-**错误!未找到引用源。**. The difference is whether the high-pressure gas generator is calculated or not. The former set up many parameters to calculate the pressure of high-pressure chamber, including the powder parameters, physical parameters and so on. The pressure result is the prerequisite of launcher tube calculation, but the latter part of the extrapolation use external data about high-pressure chamber to calculate the launcher tube. The two calculation methods mentioned above, the results of simulation are curves of average pressure, average temperature in launcher tube, missile movement distance and so on. Furthermore, according to the different entrance conditions, the simulation evaluations about interior ballistic have two parts of parameterized simulation and extrapolation simulation. The part of parameterized simulation’s pressure entrance conditions are to set up related parameters about nozzle, besides, the pressure and temperature curve obtained by the experiment are imported into the simulation module with the external files in simulation of extrapolation’s part, simulation system use it for entrance condition to calculate interior ballistics[11-15].The structure of the simulation system about interior ballistics of gas-ejection as shown in Fig.1.Engineering staff utilize the system of simulation to gain the results of pressure, temperature and gas velocity in launcher tube through two modules. By comparing these results synthetically, the parameters are constantly updated in the simulation system to obtain the optimal parameters settings, which can be applied to a missile launching. This method improves the engineering efficiency and reduces the manpower and material consumption caused by the actual experiment **错误!未找到引用源。**].

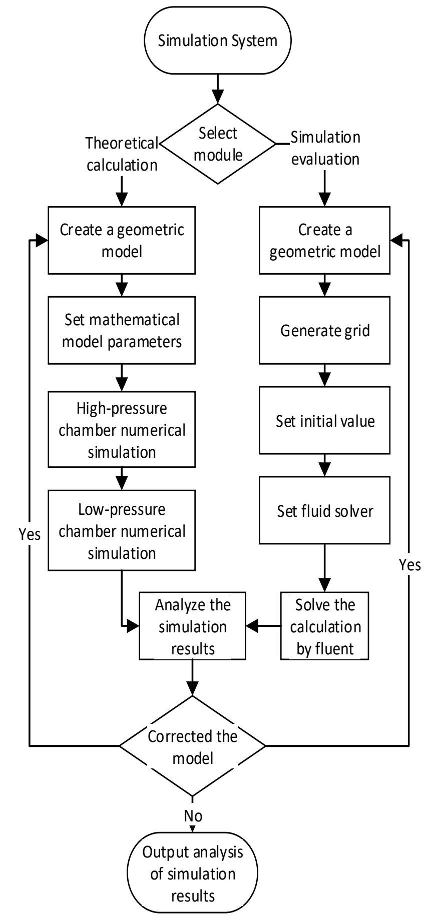

Fig.1 The structure of the simulation system

3. The realization of the zero-dimensional interior ballistic simulation

3.1 The mathematical model of high-pressure chamber (combustion chamber)

According to the knowledge of interior ballistic 错误!未找到引用源。, the zero-dimensional interior ballistic includes the mathematical models of high-pressure chamber and low-pressure chamber. Two mathematical models are closely linked and indispensable. The pressure changes in the high-pressure chamber have important impact on low-pressure chamber's pressure and temperature. What's more, it affects the process of missile ejection[16]. We can see from the reference [11], the calculation of pressure in the high-pressure chamber is divided into two parts, which are rising-balance section and post-period section[19],[20].

$$A_t = \frac{\pi}{4} {d_t}^2 \quad (1)$$

$$\Gamma = \left(\frac{2}{k+1}\right)^{\frac{k+1}{2(k-1)}} \quad (2)$$

$$e_0 = (D-d)/2 \quad (3)$$

$$V_{g0} = \frac{\pi}{4} {D_i}^2 L_c \quad (4)$$

Where d_t is the diameter of spout throat, k is specific heat ratio of gas, D is outside diameter of gunpowder, d is inside diameter of gunpowder, D_i is inside diameter of combustion chamber, L_c is part of the cylinder's length of combustion chamber. The above parameters are known parameters. According to the formula(1) to formula(4),that can calculate unknown parameters, such as the area of throat is A_t, combustion propellant thickness is e_0,initial free volume is V_{g0}. Meanwhile, three unknown parameters are obtained as known parameters of equations (5) to (8).

$$A_b = N\pi(d + 2e)L \tag{5}$$

$$V_g = V_{g0} - \frac{\pi}{4}N[D^2 - (d + 2e)^2]L \tag{6}$$

$$\frac{V_g}{\Gamma^2 {C_*}^2} \times \frac{d\overline{p}}{dt} = A_b\overline{p}^n(\rho_p \times 10^{-3} - \frac{\overline{p}}{\Gamma^2 {C_*}^2}) - \frac{\overline{P}A_t}{C_*} \tag{7}$$

$$\frac{de}{dt} = a\overline{p}^n \tag{8}$$

Where N represents the number of tubular powder; L represents the length of powder; n means pressure index and C_* is a characteristic speed; a is burning rate coefficient. As for these parameters, they are known. We should calculate the total area of burning gunpowder is A_b, the free volume in high-pressure chamber is V_g, average pressure in high-pressure chamber is $\bar{p}$ and the layer thickness of the combustion is e.

Formulas (5) ~ (8) are the pressure calculation of the rising-balance section of the high-pressure chamber. Fourth-order Runge-Kutta method widely used in engineering, which is a high-precision single-step algorithm. In view of the high accuracy of the algorithm, it meets the requirements of high-pressure chamber calculation[20]. Besides, fast convergence can make the simulation of the average pressure of high-pressure chamber with good real-time, therefore, the simulation system uses the fourth-order Runge-Kutta method to realize the above ordinary differential equations.

The initial pressure of the high pressure chamber p was 0.1MPa and the starting time t = 0 and e = 0 were set by the simulation system. After the calculation of the rising-balance section of the high-pressure chamber, comparing the combustion propellant thickness($e0$) and the layer thickness of the combustion(e),if $e<e_0$, continue the calculation of the rising-balance section, else if $e\geq e0$,let $t=t_b$, then calculating the post-period section according to equation(9).

$$\overline{p} = \overline{p}_b \times e^{-[\frac{A_t\Gamma^2 C_*}{V_{g0}}(t-t_b)]} \tag{9}$$

As shown in Fig.2, a flow chart for the calculation of the high-pressure chamber was achieved.

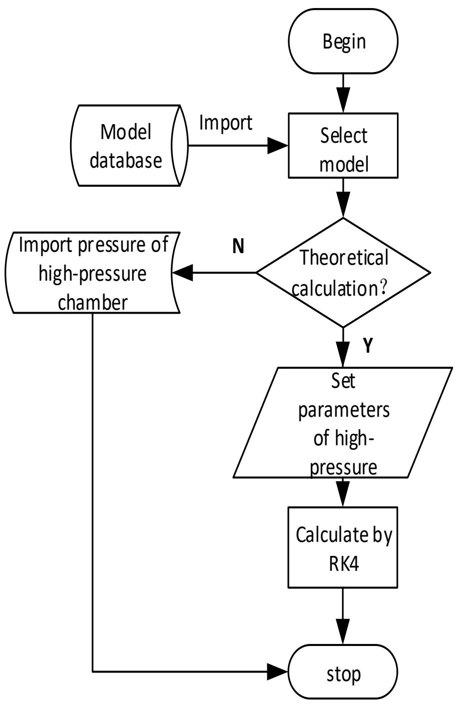

Fig.2 Flow chart of high-pressure chamber calculation

Starting with the selecting model in zero-dimensional interior ballistic simulation module, after the model was selected, then it should select calculated method. From the above we can see, there are two calculated methods under each module respectively for the theoretical calculation mode and extrapolation calculation mode[22]. Here, taking the theoretical calculation method as an example, the parameters of the high-pressure chamber were set, including the geometrical parameters of the gunpowder and the geometrical parameters of the power plant. The simulation platform uses the computer programming technology and programming the equations (1)~(9) into a class named MainJiSuan(), it is provided to the fourth-order Runge-Kutta method[26]. So that we can calculate the pressure of high-pressure chamber at each time and draw the pressure curve.

3.2 The mathematical model of low-pressure chamber (launcher tube)

Due to the low-pressure chamber ballistic characteristics have a large number of parameters[22], therefore, the simulation system only calculates the average pressure, the average temperature in launcher tube, the vertical displacement of the missile, the acceleration and the velocity .So it can output the corresponding curves. The premise of calculating the mathematical model of low-pressure chamber is neglect the inhomogeneity of gas distribution in the launcher tube[23]. The establishment of the interior ballistic equations is based on the instantaneous gas parameters, however, the actual situation is more complicated. With references [18-20], the average temperature's and pressure's equations like as fomula (10) and fomula (11)

$$t_t = \frac{x_e m_g c_{vg} t_{vg} + m_a c_{va} t_a - (\frac{1}{2} M^2 v + \int_0^l F dl)}{m_g c_{vg} + m_a c_{va}} \tag{10}$$

$$P_t = \frac{x_p (R_g m_g + R_a m_a)(t_t + 273)}{S_t (l_0 + l)} \tag{11}$$

Among equations (10)and(11),where M is the weight of missile; x_g, x_p , x_k are the coefficients of energy, pressure, motivation; m_g, m_a represent the flows of gas, air; c_{va} and c_{vg} are the isobaric heat capacity of air and gas; t_a and t_{vg} mean air temperature and gas temperature; S_t is cross-sectional area of launcher tube;l_0 represents the launcher tube's length; R_g and R_a mean gas constant of air and gas; g is gravitational acceleration; f_p is friction coefficient of adapters;P_0 represents initial pressure in launcher tube; z is a constant. The above parameters are known parameters. Using equations (10) and (11) to calculate the average temperature (t_t)and pressure(P_t) in launcher tube.

Ignoring the other forces that have been encountered during the missile movement, the system only considers the three major forces during missile movement, the forces are the gravity of the missile itself, the friction force received by the missile during its movement in the launcher tube and the air pressure at the initial moment in the launcher tube. Equations (12) and (13) are obtained from reference [12] and combined with the Newton second law.

$$F = (1 + z)Mg + (1 + x_k) f_p P_t + P_0 S_t \tag{12}$$

$$Ma = (1 + x_k) P_t S_t - F \tag{13}$$

The meanings of the parameters in the formulas (12) and (13) are the same as those in the formulas (10) and (11).According to the formulas(12) and (13),we deducted the relationships between the current missile's displacement (l_n)and velocity(v_n) , the missile displacement(l_{n-1}),velocity(v_{n-1}),acceleration(a_{n-1}) at the previous moment and get the integral equations(14) to (16).

$$l_n = l_{n-1} + \Delta t v_{n-1} + \frac{1}{2} \Delta t^2 a_{n-1} + \frac{1}{6} \Delta t^3 d(a_{n-1})/dt \tag{14}$$

$$v_n = v_{n-1} + \Delta t a_{n-1} + \frac{1}{2} \Delta t^2 d(a_{n-1})/dt \tag{15}$$

$$d(a_{n-1})/dt = \frac{a_n - a_{n-1}}{\Delta t} \tag{16}$$

The above equations (10) to (16) are realized by a numerical iterative calculation method[25],[26], using them to calculate the pressure (P_t), temperature(t_t) in launcher tube, missile displacement (l),velocity(v) and acceleration(a). The interval time of Ät set in this simulation system was 0.01s, the iterative end condition was that the missile movement displacement reached the height of the launcher tube, that is, the entire emulation process ended when the missile out of the barrel. Part of the low- pressure chamber simulation flow chart shown in Fig.3.

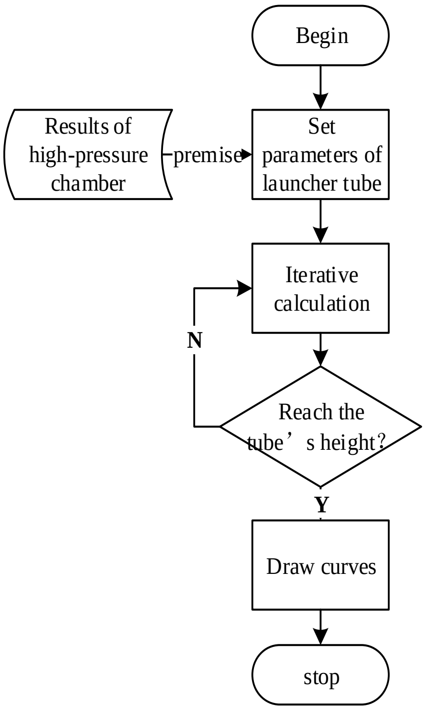

Fig.3 Flow chart of low-pressure chamber

The completion of the high-pressure chamber’s pressure calculation is the beginning of the low-pressure chamber‘s calculation, they are closely related to the calculation, and it has a great impact on low-pressure chamber’s calculation. After the setting of low-pressure chamber’s parameters, let use numerical iteration to calculate. If the missile displacement has reaches the height of launcher tube, the missile had been out of tube and completed the process of simulation. On the contrary, continue the process of iteration until reached the cylinder height.

4. The realization of the two-dimensional interior ballistic simulation

According to reference [9], the two-dimensional interior ballistic numerical simulation gives the details of gas flow in low-pressure chamber, which is in favor of the optimal design of the structure of the catapult as well as the interior ballistic experiment. However, two-dimensional numerical simulation of interior ballistics is time-consuming, requiring Computational Fluid Dynamics (CFD) software Fluent and Gambit. Gambit is responsible for the geometric mesh modeling section and Fluent is responsible for fluid modeling and calculation[24]. Grid quality by Gambit is an important foundation for the computations of flow, it’s difficult to create a good grid, what’s more, it is a utmost complicated and professional work among designers. In addition, due to the complicated physical phenomena of the gas flow field and the large number of physical parameters involved it, it is necessary to define various complicated boundary and control the moving grid[27].

It is difficult for non-professionals to use the Computational Fluid Dynamics (CFD) software to simulate the two-dimensional interior ballistic trajectory of ejection. Because the process of before and after in Gambit and Fluent is very complex. In order to solve this problem, combining the two-dimensional interior ballistic numerical simulation with the computer simulation, besides, using C# language combined with OpenGL to develop visual graphical user interface which is a professional graphical programming interface[30],[31], the structural model of the 3D weapon system using OpenGL is shown in Fig.4. This method realized the pre-processing of human-computer interaction, including parameters setting, generation and modification of grid models, fluid physical parameters setting and boundary conditions are entered and modified. The purpose of this system are solve the difficulty of analyzing the fluid mechanics and provide a interior ballistic simulation system of gas-ejection with good interaction for engineering personnel, furthermore, this system improves the efficiency of the study.

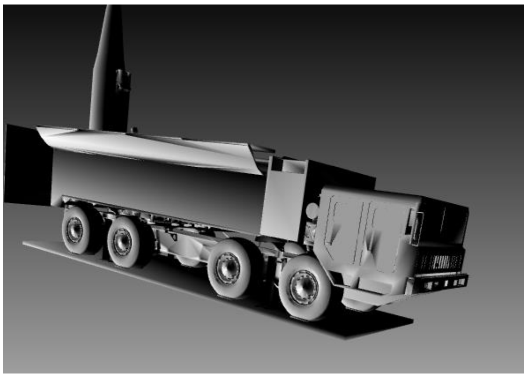

Fig.4 Three-dimensional structural model of the weapon system

This article studies gas catapults, establishing two-dimensional axisymmetric mathematical model of ejection interior ballistic according to the physical model is axisymmetric. The two-dimensional axisymmetric control equation is adopted as the governing equation of flow solver, energy transfer and chemical reaction, the specific equations are found in references [11,12].The simulation system's flow-process diagram for two-dimensional numerical simulation of interior ballistics shown in Fig.5.

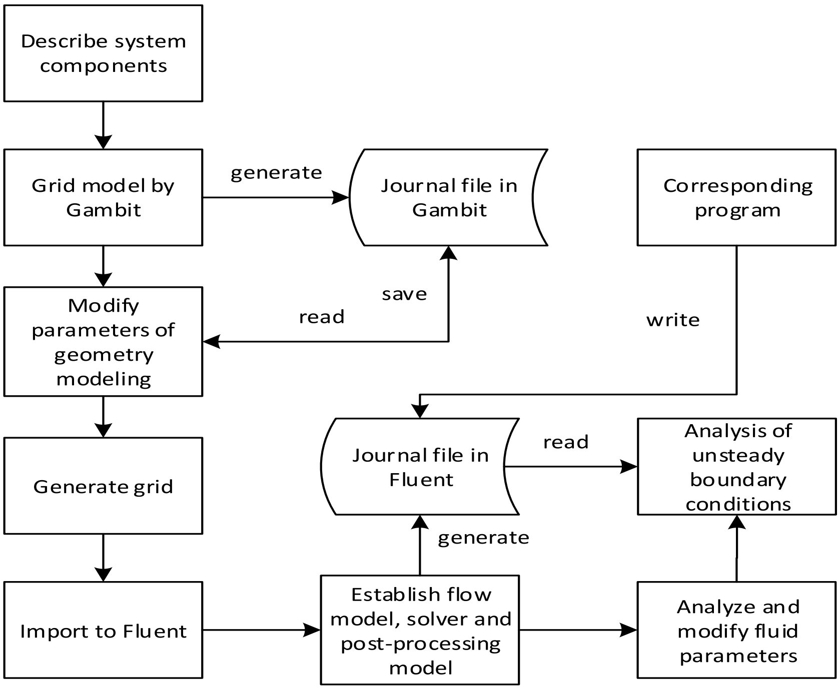

Fig.5 Flow-process diagram for two-dimensional numerical simulation of interior ballistics

In order to complete the data exchange with the Computational Fluid Dynamics(CFD) software under the .Net platform, we use the C# language in the simulation system to redevelop Gambit and Fluent software[24]. The second development of the specific process is described in detail in reference [11]. It can be seen from Fig.5, that two-dimensional numerical simulation of gas-ejection trajectory requires creating grid model, setting of boundary conditions and establishing flow model. The constructed grid model is axisymmetric owing to the primary chamber is a two-dimensional axisymmetric model, the physical model is shown in Fig.6. Half of the primary chamber grid model is shown in Fig.7. The .msh files were imported into the Fluent software for calculation, which was built in Gambit. Because this paper studied for two-dimensional interior ballistic numerical simulation, its calculation would spend a lot of time, we selected 2D solver to calculate in order to shorten the time. This step was implemented in the background with computer programming technology and engineers don't need to set up a solver[20].

The initial conditions and boundary conditions for fluid calculation were set up as follows:

(1) Initial conditions: the initial pressure of the primary chamber used standard atmospheric pressure, the value was 101325Pa and the initial time temperature of the primary chamber was 293K here.
(2) Boundary conditions: Wall thickness of 0.005m in Fluent software and the wall heat exchange coefficient of 50W / (m^2 * K).

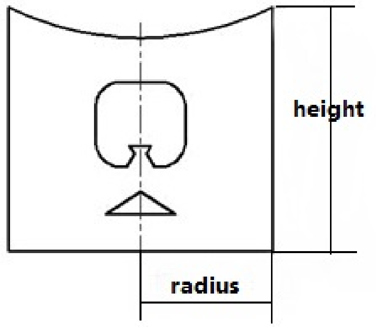

Fig.6 The model diagram of the primary chamber

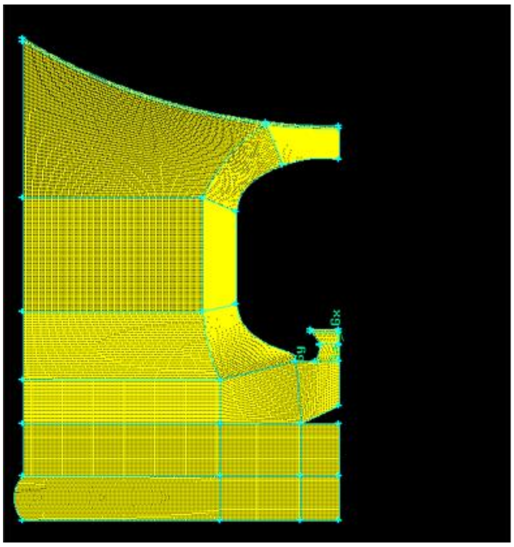

Fig.7 The grid model of the primary chamber

5. Analysis of the result of simulation example

Taking zero-dimensional and two-dimensional numerical simulation of the interior ballistic by using the gas-ejection trajectory interior ballistic simulation system was developed in this paper. All the parameters were set up as shown in Tab.1 to Tab.4. They represent the parameters of high-pressure and low-pressure chamber, geometric modeling and hydrodynamics. In this case, the same data was used for the high-pressure chamber and the low-pressure chamber in the zero-dimensional and two-dimensional numerical simulations, so that the interior ballistic curves may the same that were obtained in two simulations. The detailed parameters of two-dimensional interior trajectory numerical simulation about flow field numerical simulation were shown in Tab.3 and Tab.4. The specific simulation results were described in detail as below.

Tab.1 The parameters of high-pressure chamber

Parameter name	**Value**	**Parameter name**	**Value**
gunpowder's length（L）	0.25m	tubular powder's number（N）	24
gunpowder's outer diameter（D）	0.1m	gunpowder's inside diameter（d）	0.018m
gunpowder's density（$\tilde{n}_p$）	1600kg/m^3	pressure index of gunpowder（n）	0.335
burning rate coefficient（a）	0.00029m/s*pa^n	the gas specific heat ratio（k）	1.27

DOI https://doi.org/2024-JICS-22417 | Generated on 2025-04-15 10:49:07

High-pressure chamber's diameter（L_c）	0.684m	High-pressure chamber's height（D_c）	0.308m
nozzle throat's diameter（d_t）	0.126m		

Tab.2 The parameters of low-pressure chamber

Parameter name	**Value**	**Parameter name**	**Value**
missile's weight（M）	44145kg	gravitational acceleration（g）	9.8m/s^2
adapter's friction coefficient（f_{fi}）	0.02	primary chamber's height（l_0）	1.4m
Launcher tube's diameter（D_t）	2.1m	launcher tube's air quality（m_a）	17.7m
pressure coefficient（x_p）	1	kinetic energy coefficient（x_k）	0
the product of the flow coefficient and the recovery factor（k_1）	1	energy coefficient（x_e）	1.3
gas temperature（t_g）	1070℃	gas constant volume specific heat(C_{vg}）	1510 J/kg*K
gas constant（R_g）	417.8 J/kg*K	air temperature（t_a）	20℃
air constant volume specific heat（C_{va}）	717 J/kg*K	air constant（R_a）	287 J/kg*K

Tab.3 The geometric modeling parameters

Parameter name(unit)	**Value**	**Parameter name(unit)**	**Value**
nozzle entry radius(mm)	93	nozzle exit radius(mm)	78
nozzle expansion length (mm)	51	nozzle contraction length (mm)	40
nozzle throat radius（mm）	63	guiding cone's height(mm)	60
the distance from the bottom of the primary chamber to the nozzle(mm)	530.35	distance between the diversion cone and the outlet of the nozzle(mm)	148.3
primary chamber's height(m)	1.4	guiding cone's tilt angle(°)	25.24
launcher tube's radius(m)	1.05	Launcher tube's height(m)	17.7
missile weight(kg)	44145	adapter's friction coefficient	0.02

Tab.4 The hydrodynamics parameters

Parameter name(unit)	**Value**	**Parameter name(unit)**	**Value**
gas temperature(℃)	1070	Gas constant pressure heat(J/kg*K)	1510
gas's average molecular weight(g/mol)	20	Primary chamber's initial pressure(Pa)	101325
Primary chamber's initial temperature(K)	293	wall thickness(mm)	5
wall heat exchange coefficient(W/m^2*K）	50		

5.1 Characteristic curves of interior ballistic

Analysis of zero-dimensional and two-dimensional interior ballistic numerical simulation in this paper, the simulation results were the average pressure of the launcher tube, the average temperature curve of the launcher tube, the acceleration, the velocity and the displacement curve of the missile. The simulation results were shown in Fig.8 to Fig.12.

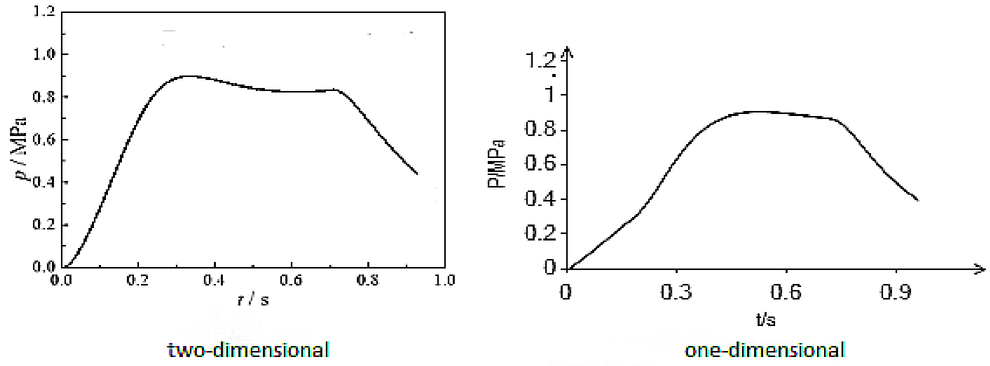

Fig.8 The average pressure of the launcher tube

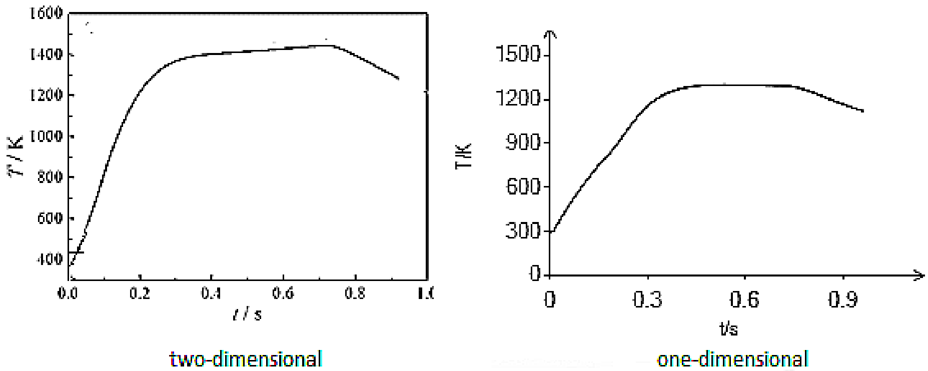

Fig.9 The average temperature curve of the launcher tube

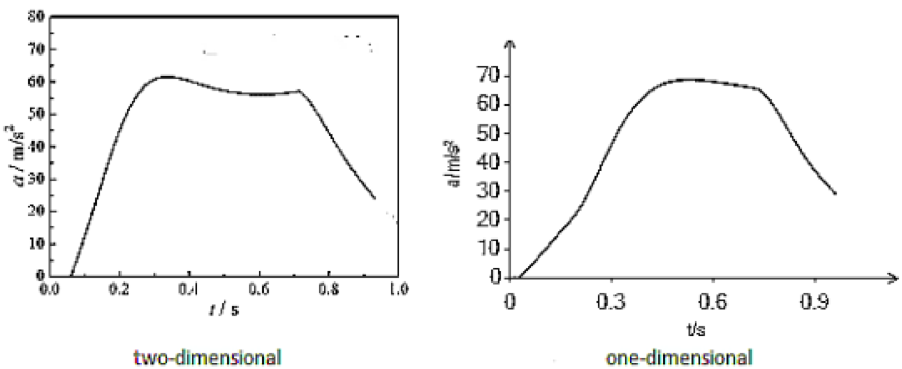

Fig.10 The acceleration curve of the missile

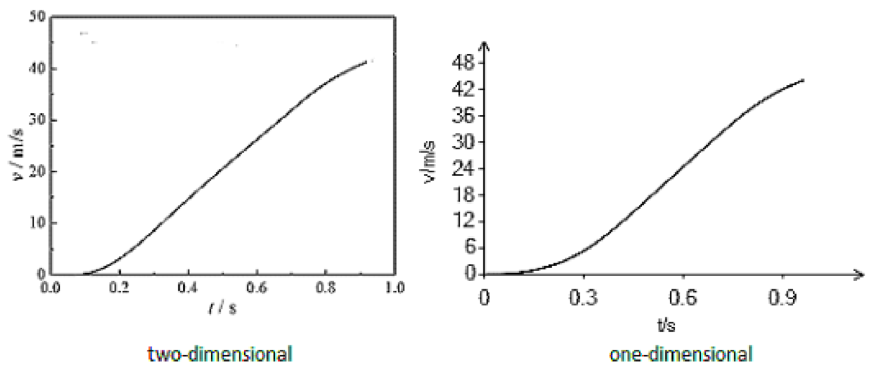

Fig.11 The velocity curve of the missile

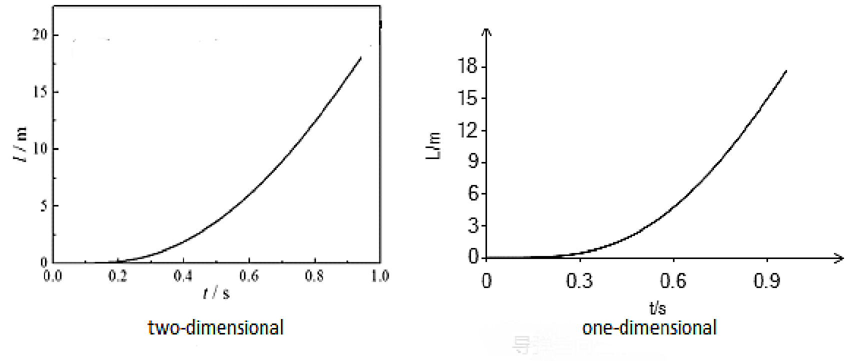

Fig.12 The displacement curve of the missile

As we can be seen from Fig.8 to Fig.10, within 0.3s of the beginning of the grain combustion and within 0.2s of the end of the grain combustion, the average pressure and the average temperature in the launcher tube, the vertical acceleration of missile were in an unstable state, only in the middle of a period of time, the curves of interior ballistic characteristics in a more stable state because the drug column in a state of stable combustion, so, the pressure, temperature and acceleration would not fluctuate greatly because the power generated was stable.Fig.11 and Fig.12 represent the velocity and displacement of the missile. It is known from kinematic knowledge that the displacement and the velocity of the missile are always increasing if the acceleration increasing[29]. It can be concluded that the zero-dimensional interior ballistic simulation curve was consistent with the trend of the two-dimensional interior ballistic simulation curve by comparing the simulation output curves.

Tab.5 Comparisons of two-dimensional and zero-dimensional interior ballistic simulation results

parameters	two-dimensional	zero-dimensional
maximum pressure at launcher tube/moment	0.9156MPa/0.38s	0.9041MPa/0.52s
maximum temperature at launcher tube/moment	1491K/0.78s	1301K/0.53s
missile's maximum acceleration/moment	64 m/s^2/0.38s	69 m/s^2/0.52s
missile's velocity out of the tube	43.4 m/s	44.2 m/s
missile's moment out of the tube	0.903s	0.963s

The maximum of pressure, temperature in the launcher tube and acceleration of missile were not quite different according the data from Tab.5, the difference between two-dimensional and zero-dimensional simulation results were less than 5%. The length of the launcher tube studied in this paper was 17.7m. When the vertical displacement of the missile reached the height of the launcher tube, the entire simulation process was completed. In the two-dimensional and zero-dimensional interior ballistic simulation, the missile's velocity out of the tube was 43.4m/s and 44.2m/s at the moment was 0.902s and 0.963s respectively.

We can see from the above analysis that the simulation results of zero-dimensional and two-dimensional internal trajectory were mutually supportive, and the conclusion has certain reference meaning that was drawn in the gas-ejection interior ballistic simulation system developed in this paper. It is worth to use by researchers to improve the efficiency of its numerical simulation and provide theoretical support for the design of the projectile missile. Non-professionals can conduct two-dimensional numerical simulation of internal trajectory without having to master the use of Computational Fluid Dynamics (CFD). To a certain extent, it solved the problem that hydrodynamics pre-treatment and post-treatment are too complicated. The emergence of the simulation software opens a shortcut for the numerical simulation of gas-ejection interior ballistics.

5.2 Flow field pictures of interior ballistic

Compared with the zero-dimensional interior ballistic mathematical model, the two-dimensional interior ballistic mathematical model was better describe the characteristics of the interior ballistics of gas-ejection in low-pressure chamber, especially the pressure and temperature distribution characteristics of the low-pressure chamber and the gas flow velocity. In the two-dimensional interior trajectory numerical simulation module, engineers simulate the missile's launching system by using the Computational Fluid Dynamics(CFD) software and output the pictures ,which were the pressure and temperature of the launcher tube at any time. Besides ,the picture of gas flow velocity in the launcher tube also was outputted in simulation. An example of this simulation, the boundary conditions established by numerical simulation of two-dimensional interior trajectory . They were the initial pressure of high-pressure chamber was 0.1MPa, the initial temperature was 293K, the mass of missile was 44145Kg and the throat radius of nozzle was 63mm. From the above analysis we can see that in the process of interior ballistic simulation, the characteristic of the whole interior ballistics was stable at 0.3s, and the images of the flow field at the 0.3s moment obtained by the two-dimensional interior ballistic simulation module were shown in Fig.13 to Fig.15. Analysis of the cloud picture showed that the pressure inside the launcher tube was around 722154Pa, the temperature was about 1304K, and the gas velocity was below 10m/s, which were consistent with the above mentioned internal-ballistic curves.

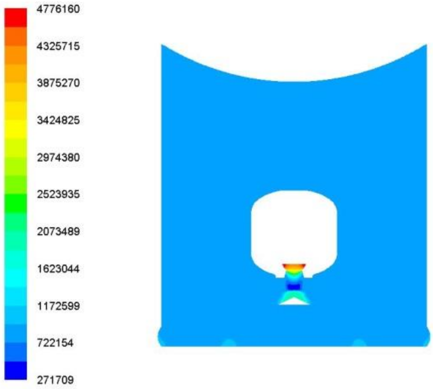

Fig.13 Pressure's field cloud picture at 0.3s

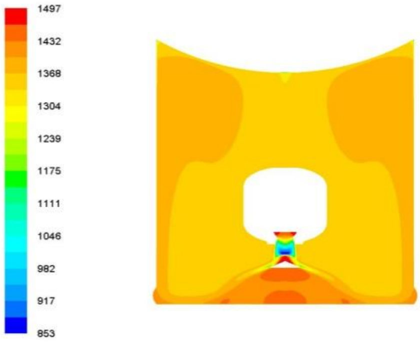

Fig.14 Temperature's field cloud picture at 0.3s

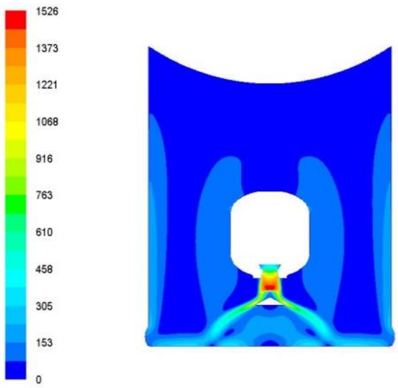

Fig.15 Velocity's field cloud picture at 0.3s

6. Conclusions

In this paper, the simulation system about interior ballistics of gas-ejection was developed with computer simulation, which provided a visualized operation platform with good interactivity for researchers who study the ejection of ballistic trajectory. By creating the interior ballistic model for zero-dimensional and two-dimensional numerical simulation, users set the parameters of the interior ballistics in the visualization interface to repeat simulation and get the simulation results to generate the data report for professionals to use. The development of this simulation platform solves the problems of large-scale numerical simulation and creating model of ejection interior ballistic launch system. It provides a stable and reliable simulation system for ejection interior ballistic engineering designers and gives theoretical and technical support for the estimation of gas flow field parameters in practical experiment.

The simulation platform has been used by the relevant domestic units and achieved very good results. In the future research, the system is continuously perfected to realize the numerical simulation of the gas flow field of the launching system on different platforms, which carry out the fluid mechanics and dynamics analysis and provide a more complete simulation platform for the gas flow field simulation of the launching system in the military field.

Acknowledgments

This work is financially supported by the Science Research Funds of Anhui Provincial Education Department in China (No.KJ2017ZD05) and Natural Science Funds of Anhui Provincial Education Department in China (No. KJ2016A085).

Conflict of Interest The authors declare that they have no conflict of interest.

References

[1]. Zheng Gang Xiao,San Jiu Ying,Wei Dong He,Fu Ming Xu. A Novel Interior Ballistic Prediction of Gun Propellants Based on Experimental Pressure-Apparent Burning Rate Model in Closed Vessel. Advanced Materials Research,2013,2295(668k).

[2]. V. F. Bolyukh,A. I. Vinnichenko. Concept of an Induction-Dynamic Catapult for a Ballistic Laser Gravimeter. Measurement Techniques,2014,56(10),1098-1104.201.

[3]. Xiao-chun Xue,Yong-gang Yu,Jin-ming Xie. The influence of nozzle diameters on the interaction characteristic of combustion-gas jets and liquid. Defence Technology,2017,13(4)

[4]. Kazuhisa Chiba,Masahiro Kanazaki,Atthaphon Ariyarit,Hideyuki Yoda,Shoma Ito,Koki Kitagawa,Toru Shimada. Multidisciplinary Design Exploration for Sounding Launch Vehicle using Hybrid Rocket Engine in View of Ballistic Performance. International Journal of Turbo & Jet-Engines,2015,32(3).

[5]. Ruihua Zhang,Xiaoting Rui,Yan Wang,Chao Li. Study on Dynamic Burning Rate Equation of Propellant. Propellants, Explosives, Pyrotechnics,2017,42(6).

[6]. Cheng Cheng,Xiaobing Zhang. Influence of serial and parallel structures on the two-phase flow behaviors for dual combustion chambers with a propelled body. Powder Technology,2016.

[7]. Yu. I. Shokin,K. E. Afanas'ev. Application of the natural element method for solution of problems of fluid dynamics with free boundaries. Russian Journal of Numerical Analysis and Mathematical Modelling,2011,26(5).

[8]. WANG Li,ZHANG Xue – feng. Numerical Simulation of Propellant Combustion on Launch of New Type Gas Generator.Computer Simulation. 2014,12:37-40+97

[9]. Enzhe Song,Zhenting Liu,Liping Yang,Chong Yao,Jun Sun,Quan Dong. Effects of nozzle structure on the gas mixture uniformity of marine gas engine. Ocean Engineering,2017,142.

[10]. TAN DA cheng,MIAO Pei yun. Two-dimensional Interior-ballistic Model and Numerical Research on Low-pressure Chamber of Catapult.Journal of Projectiles,Rocket,Missiles and Guidance. 2006,(04):224-226.

[11]. Chen YaJun. Numerical Simulation and Parameter Design On Missile Gas-ejection Interior Ballistic. AnHui University of Technology.2017.

[12]. LI Xiang-yang,HUANG Xian-xiang,GAO Qin-he,ZHANG Zhi-li.Development of Visual Simulation Platform for Interactive Missile Launching System.Journal of System Simulation. 2009,21(2):140-160.

[13]. Xue Yuan Long,Zhi Jun Li,Yuan Tian. Application of Ejector Technology to the Efficient Exploitation in the Low-Pressure Gas Well. Applied Mechanics and Materials,2013,2755(433).

[14]. JIANG Shu-yuan,WANG Hao,RUAN Wen-jun. Two-dimensional Interior Ballistics Model of High Pressure Ejection Apparatus and Analysis on the Characteristics of Flow Field in Launching Chamber. Acta Armamentarii.

2015,36(6):1010-1014.

[15]. Jin-zhu Yang,Zhao-fei Wang. Numerical Simulation of Launch Tube Based on Container–type Missile Launch Technology. Procedia Engineering,2012,31.

[16]. KONGF De-jin,CHEN Li-yun,JIN Meng. Design of Ground-to-Air Missile Battalion Firepower Simulation System Based on HLA.Computer Engineering. 2011,37(15): 252-255.

[17]. Jun Hua Bai,Chun Bo Hu,Jia Ming Li. The Interior Ballistic Research for Gas-Steam Launching System with Water Injection in Block. Applied Mechanics and Materials,2012,2047(232).

[18]. Chen Qinggui,Qi Qiang,Zhou Yuan,Zhao RuYan,Wang Bin.Interior Ballistic Research on Gas and Steam Launch Power System.2013:81-85.

[19]. Jin-zhu Yang,Zhao-fei Wang. Numerical Simulation of Launch Tube Based on Container–type Missile Launch Technology. Procedia Engineering, 2012,31.

[20]. K. J. In't Hout, M. N. Spijker. Stability analysis of numerical methods for delay differential equations. Numerische Mathematik, 1991, 59 (1).807-814

[21]. Mukaddes Ökten Turacý, Turgut Öziþ. Derivation of three-derivative Runge-Kutta methods. Numerical Algorithms, 2017, 74 (1), 247-265

[22]. Hazem EI Sadek,Xiaobing Zhang,Mahmoud Rashad,Cheng Cheng,Robertt A Fontes Valente. Improvement of Interior Ballistic Performance Utilizing Particle Swarm Optimization. Mathematical Problems in Engineering.2014.

[23]. Ling Ke Zhang,Yong Gang Yu,Xin Lu. Interior Ballistics Simulation of Modular Charge Gun System Using Matlab.Applied Mechanics and Materials.2012(195).

[24]. Zhen Yu Ma. Calculation for Flow Field and Motion of the Missile Capsule in Launching Tube. Applied Mechanics and Materials,2011,1229(52).

[25]. Suheil Khuri,Ali Sayfy. A Class of Boundary Value Problems Arising in Mathematical Physics: A Green's Function Fixed-point Iteration Method. Zeitschrift für Naturforschung A,2015,70(5).

[26]. Juan Zhang. The numerical solution of fifth-order boundary value problems by the variational iteration method. Computers and Mathematics with Applications,2009,58(11).

[27]. Na Zhao,Yong Gang Yu,Yu Qiang Wang. Numerical Simulation of the Spray Characteristics in Small Scale Liquid Rocket Engine Combustion Chamber.Advanced Materials Research.2012(383)

[28]. Yongquan Liu,Anmin Xi. An Interior Trajectory Simulation of the Gas-steam Missile Ejection. Journal of Computers,2013,8(5).

[29]. Carmen Chicone. Chapter 11 - Equations of Fluid Motion.Elsevier Inc.:2017-06-15.

[30]. Yao Wang,Li Xia Sun,Jiu Chen Fan. Application of OpenGL in NC Turning Simulation. Advanced Materials Research,2012,1767(505).

[31]. Nakhoon Baek. Design of OpenGL SC 2.0 Rendering Pipeline.Springer Singapore:2017-06-15.