Research on Accurate Impact Point Prediction Methods of Heavy Rocket Debris

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Abstract: Driven by the demands of rocket launching safety and major scientific research projects, this study probes into the process of impact point prediction for heavy debris from rocket launching. By establishing the basic model of impact point prediction, an analysis of error sources of impact point prediction is conducted to define the research direction of improving the accuracy of impact point prediction. The calculation model of heavy debris impact points introduces the concept of comprehensive analysis of big data. Based on the current situation of equipment, it makes full use of valuable measured data resources of rocket launching and the data information of the measured flight and landing area in multiple samples. Using statistical methods, a back calculation of air resistance and velocity correction affecting the impact point calculation is made, thus forming an accurate calculation model of heavy debris impact points. The data validation shows that the real-time prediction accuracy of this model has been greatly improved compared with the original model, which meets the research expectations.

1. Introduction
In the process of space launch test, the safety of debris landing area is an important part in the design of space launch scheme. During the space launch, the fast recycling of unpowered heavy debris and emergency rescue are also crucial for the recycling in the landing area. The calculation accuracy of heavy debris impact points directly affects the design of space launch schemes, the rapid recycling of debris by the ground personnel and the implementation of after-calamity rescue missions. It is a basic requirement for the safety of space launch, and is also important for debris recycling and rescue.

In order to meet the higher requirements of high-density launch missions on the safety of landing area in recent years, in accordance with the actual needs of landing area planning and impact point prediction, the present study proposes a new calculation model of real-time impact point prediction for unpowered heavy debris. By using the measured data of impact points collected from multiple missions, the model is based on the calculation and statistics of massive data.

2. Overview of Impact Point Prediction

2.1 Task Requirements of Impact point Calculation
In the space launch mission, three main functions are required to support impact point calculation. The first is in the stage of designing launch window and flight trajectory. In this stage, the function of accurate impact point calculation is required for a safety analysis of landing areas at each sub-level, landing areas at the first and secondary levels as well as the booster impact point in particular, conducted on the designed flight trajectory, with an aim to ensure that the impact points of rocket debris are far away from the national key safety areas such as metropolises, densely-populated areas, major factories and mines, and also to avoid the debris falling into neighboring countries or their own
exclusive economic zones, thus reducing economic losses, casualties and political disputes. The second is in the stage of ground safety control during the flight mission. In this stage, the function of real-time impact point calculation is required for the real-time calculation of rocket landing areas, which provides information support for the selection of safety control impact points and is considered as an important basis for security officers to make safety control decisions. The third is in the stage of debris recycling and rescue. In this stage, the function of impact point prediction is required for a fast calculation of locations of impact points at sub-levels with higher accuracy so that the search and rescue team in landing areas can quickly carry out the task of debris recycling and rescue.

2.2 Principles of Impact Point Calculation

For impact point calculation, the motion of the unpowered trajectory segment of the debris can be considered as particle motion. The flight of the unpowered trajectory segment is mainly affected by gravity, Coriolis force and air resistance only in terms of the principles of object kinematics. The flight of the unpowered trajectory segment can be divided into free-flight trajectory and reentry trajectory in terms of force. The debris in the free-flight trajectory only moves under the Coriolis force caused by the gravity and rotation of the earth. The difference between free-flight trajectory and reentry trajectory only lies in the presence of air resistance. Therefore, the trajectory motion of the debris impact points can be worked out by numerical integration. The instantaneous velocity and position of the debris is taken as the initial value of the motion equation (formula 1) which serves as the motion parameter at the moment of separation point. The trajectories involved in this paper are calculated by using the No.2 geocentric coordinate system, initial trajectory velocity \( \mathbf{v}_k \) and position \( \mathbf{x}_k \).

\[
\begin{align*}
\begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{z}
\end{bmatrix} &= -\frac{X_D}{m_d} \begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{z}
\end{bmatrix} + \begin{bmatrix}
g_x \\
g_y \\
g_z
\end{bmatrix} + \begin{bmatrix}
a_{cx} \\
a_{cy} \\
a_{cz}
\end{bmatrix} \\
\begin{bmatrix}
\dot{x}_k \\
\dot{y}_k \\
\dot{z}_k
\end{bmatrix} &= \begin{bmatrix}
\dot{x}_k \\
\dot{y}_k \\
\dot{z}_k
\end{bmatrix} = \begin{bmatrix}
x_k \\
y_k \\
z_k
\end{bmatrix}
\end{align*}
\]

where \( X_D \) is the air resistance, \( \begin{bmatrix} g_x \ g_y \ g_z \end{bmatrix}^T \) is the gravitational acceleration, and \( \begin{bmatrix} a_{cx} \ a_{cy} \ a_{cz} \end{bmatrix}^T \) is the Coriolis acceleration.

2.3 Process of Impact Point Calculation

The process design is based on the principles of impact point calculation. The first is to obtain the information of separation points. Secondly, the trajectory of separation points is taken out to be independently calculated. The third is to make numerical iterative calculations according to the dynamic equation of motion. Finally, the calculated trajectory information is converted into the geodetic longitude and latitude of the impact points or other information needed for display and viewing.

Figure 1. Process of Impact Point Calculation

The sources of impact point information mainly include flight trajectory and separation time. In real-time prediction and calculation of impact points, the acquisition of information is very important.
In conventional satellite launches, there is no corresponding measurements and tracking information after the sublevels are separated, and the remote and external measured signals are greatly disturbed during the separation; The theoretical trajectory and the separation time of sublevels are needed for the safety analysis and calculation of landing areas before launch. The acquisition of separation information in real-time impact point calculation is to be analyzed in detail in the next chapter.

After obtaining the information of the separated debris, this information is used as the initial value to calculate the impact points by numerical iteration in order to realize the prediction of impact points. There are many iterative calculation methods. Generally, the direct iterative calculation with a 2 ms-step size is adopted, or the “Runge Kutta” model with a 5 ms-step size is used for iterative calculation. The termination mark of iterative calculation is generally set as the elevation H of the impact points relative to the surface of the earth ellipsoid is less than 700 m. The results of iterative calculation are the position and velocity information of the debris under the geocentric system, expressed in a way that is not convenient to identify the location of the impact points. So in general, it is necessary to convert the results into the form of geodetic longitude and latitude and elevation (altitude) to represent the impact points.

2.4 Error Analysis of Impact Point Calculation

According to the principles and process of impact point calculation, there are several reasons for the errors between the calculating results and the actual impact points during the launch of the vehicle as described in the following.

a. Errors of Trajectory Information at the Separation Time of the Launch Vehicle

After the separation of the debris of the launch vehicle, except for a short reentry trajectory before the final landing, the launch vehicle has been flying in the free-flight trajectory for most of the time. However, the free-flight trajectory is only subject to the gravity and rotation of the earth, in which the motion law can be expressed more accurately. According to the motion equation (1), the falling motion of the debris mainly depends on the initial velocity and position parameters of powered trajectory segment. However, in fact, there are many interference factors during the separation process of the launch vehicle at each sub-level. Through the analysis of a large number of previous data, there are large deviations in the telemetry trajectory, GNSS trajectory and ground external measurement results in 3 seconds before and after the separation. In addition, there is no measurement equipment for the continued tracking of the separated debris. Through the statistical calculation of a large number of historical results, the actual errors of debris separation motion parameters account for more than 65% of the prediction errors of impact points. As a result, the accuracy of impact point prediction mainly depends on the acquisition accuracy of trajectory information at the separation time of the launch vehicle.

b. Calculation Errors of Initial Trajectory Information of Debris

In general, satellite launching is different from manned space flight recycling mission. There is no measurement equipment for the continued tracking after the debris of each sub stage is separated. Thus, in the process of impact point calculation, the initial motion information of the debris can not be obtained by direct measurement but is estimated by the trajectory information of the launch vehicle at the time of separation. The reason why it is estimated instead of being accurately calculated by model is mainly because the motion vector of the rocket body is too complex at the time of separation (in addition to accelerated motion in the shooting direction, the relative motion direction of the rocket body also has to do with vectors such as azimuth, pitch and rolling) and the relative force, direction and action time during the process of separation are all fuzzy control variables. Since it is difficult to calculate accurately, the task can only be corrected by using the model based on empirical values. It is in this case that this study introduces a calculation method based on statistics. Admittedly, such a method will be phased out with the improvement of measurement mode.

c. Calculation Errors of Block in the Re-entry of Debris into the Atmosphere

In the equation of motion (1), the item of air resistance is expressed as $X_D$: 
\[ X_D = C_D \left[ \frac{1}{2} g_0(\rho/\rho_0)v^2 \right] S_M \]  

In the above equation, \( S_M \) denotes the area of windward side of the debris; \( \nu \) refers to the comprehensive velocity of the debris; \( g_0 \) represents the ground gravitational acceleration; \( \rho/\rho_0 \) indicates the air density related to the height which can be obtained from the atmospheric density table of the landing area; \( C_D \) is the air resistance coefficient whose value is related to the velocity of the debris and can be obtained from the air resistance coefficient table corresponding to the Mach number.

From the formula (2), it can be seen that in the actual implementation of the task, the accurate value of the area of the windward side of the debris is not easy to obtain, and that the air density which varies with the height of the debris is not accurate enough. All of these constitute the factors that lead to the inaccurate calculation of atmospheric resistance.

d. Calculation Errors of Motion Model

The impact point calculation is a differential equation consisting of motion equation. In the numerical calculation, it is necessary to design a certain step size for iterative calculation. It is very important to select an appropriate step size, especially in real-time tasks. If the step size is too small, it will lead to an excessive amount of calculation and thus affect the real-time requirements; if the step size is too large, it will cause excessive calculation errors.

In the actual satellite launching test, the sampling frequency of the measured data is fixed; the flight velocity of the debris after separation reaches a magnitude of several thousand meters per second, and the step size of iterative calculation is a magnitude of tens of meters. In addition, the termination condition of iterative calculation is the actual elevation of the impact point, but the relative height of the debris on the surface of the earth ellipsoid is difficult to be consistent with the control value of the impact point, which will result in errors in a magnitude of hundreds of meters.

3. Key Technologies of Impact Point Calculation

Theoretically, the actual impact point of the debris is a fixed value, but due to the influence of various errors, measurement accuracy and other factors, the impact points of the debris are generally distributed in a concentrated area, and the actual impact point is within this area. The main idea of the impact point prediction model based on the statistical analysis of the impact points from multiple missions is to classify the unknown or not thoroughly corrected errors based on the study of impact point calculation and error correction methods and then integrate them into the calculation model of impact points as the unknown variables. Finally, the impact point calculation model based on statistical analysis is formed by comparing the impact point information with the measured data of the debris from multiple missions to determine the unknown correction values.

According to the calculation process of impact points, this chapter analyzes and introduces the calculation methods and models involved one by one.

3.1 Acquisition of Separation Information Based on High-order Fitting

The first step of debris impact point calculation is to know the trajectory information at the time of debris separation, and then conduct numerical calculation according to the acceleration. The separation information acquisition here is mainly used in real-time mission impact point prediction and post-mission impact point calculation and analysis. This step is not required in the safety planning and demonstration of impact points by using theoretical trajectory.

The main reason why the high-order fitting calculation is used here is that the acceleration of the main body of the rocket changes greatly before and after the separation of the debris. If the linear fitting calculation is used, the error of calculation results will be large. The trajectory information before and after the separation is respectively fitted in the model and finally the two sets of results are used to obtain the average value. In the specific calculation, 40 sets of trajectories (frame frequency: 10 frames/second) are used before and after the separation for external measurement and GNSS trajectories; for telemetry trajectory, 10 sets of trajectories (frame frequency: 1 frame/second) before and after the separation are used for calculation.
Set \( y_j, j = 1, 2, \ldots, n \) as the measured value at the \( j \)\(^{th}\) sampling point of the parameter time sequence \( t \) of the trajectory \( x, y, z, V_x, V_y, V_z \); \( b_j \) denotes the polynomial regression coefficient of the \( y_j \) sequence; \( p \) is the order of the fitting polynomial (taken as 2, 3, 4\( \ldots \)); \( n \) is the number of impact points in the fitting segment of polynomial regression (40 for external measurement and GNSS trajectories, and 10 for telemetry trajectory). The calculation model is shown as follows:

\[
B = (D^T D)^{-1} D^T
\]

In this model:

\[
D = \begin{bmatrix}
1 & t_1 & t_1^2 & \cdots & t_1^p \\
1 & t_2 & t_2^2 & \cdots & t_2^p \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
1 & t_n & t_n^2 & \cdots & t_n^p
\end{bmatrix},
Y = \begin{bmatrix}
y_1 \\
y_2 \\
\vdots \\
y_n
\end{bmatrix},
B = \begin{bmatrix}
b_0 \\
b_1 \\
\vdots \\
b_p
\end{bmatrix}
\]

\( b_j, j = 1, 2, \ldots, p \) is the polynomial regression coefficient to be solved; \( p \) is the polynomial order to be solved; \( t_i, i = 1, 2, \ldots, n \) is the time corresponding to the trajectory sequences; \( y_i, i = 1, 2, \ldots, n \) is the value in the trajectory information.

\[
y = b_0 + b_1 x + \cdots + b_p x^p, p = 2, 3, \ldots
\]

The formula (5) is the least square nonlinear fitting equation. The fitting trajectory information can be generated by putting separation time into the above formula. In this paper, the order of fitting polynomial is taken as 4.

### 3.2 Block Calculation Method Based on General Atmospheric Model

The derivative process of vector model of atmospheric blocking acceleration is more complicated, so technically it is necessary to take into consideration the atmospheric density and wind direction in the airspace during the landing process of the debris. In actual missions, the general atmospheric density data of the landing area is often used for calculation. The model described here is based on the conventional atmospheric resistance model. By analyzing the distribution law of atmospheric density that varies with the height \( h \), the index of atmospheric density varying with the height is fitted by the least squares. In combination with the influence of rocket debris section, weight and Mach number, the atmospheric block model containing the comprehensive coefficient of atmospheric block, the influence coefficient of Mach number and the atmospheric density index is established.

\[
\begin{align*}
g_{bx} &= -kV_x V_{10^{-id}} k_v \\
g_{by} &= -kV_y V_{10^{-id}} k_v \\
g_{bz} &= -kV_z V_{10^{-id}} k_v
\end{align*}
\]

The index \( i_d \) is a high-order fitting value related to the height (km). Since the data source of the impact points studied in this paper comes from the measured impact points of the launch vehicle and the booster, according to the characteristics of the fitting parameters, the equation is obtained as follows:

\[
i_d = \begin{cases}
a_1 h_k + a_2 h_k^2 + \ldots + a_9 h_k^8 & (h_k < 125) \\
b_1 h_k^6 + b_2 h_k^2 + \ldots + b_6 h_k^6 & (h_k \geq 125)
\end{cases}
\]

The parameter \( k_v \) is a fitting value related to the Mach number \( (c_v = V/340.0) \) of the debris in flight missions.

\[
k_v = \begin{cases}
1.0 & (c_v \geq 1.5) \\
0.9 + (c_v - 1) \times 0.2 & (1.5 > c_v \geq 1.0) \\
1.8 \times c_v - 0.9 & (1.0 > c_v \geq 0.75) \\
0.45 & (c_v < 0.75)
\end{cases}
\]

### 3.3 Gravitational Acceleration Model

In the process of debris falling, the debris has no power system to work. Apart from the influence of
atmospheric resistance in the process, it is also affected by gravity. The gravity here generally refers to the gravity of the earth and the Coriolis force generated by the rotation of the earth. The gravity is the most influential in the process of debris falling. The calculation model is as follows.

Suppose that the comprehensive gravitational acceleration is \( g_d \), and then the three acceleration components in the direction of motion are \( g_{xd}, g_{yd}, g_{zd} \), respectively. Their expression equations are presented as follows:

\[
\begin{align*}
    g_{xd} &= \frac{x_d}{r_d} g_1 + x_d w^2 \frac{\phi}{r_d} + 2 w_v v_{dy} \\
    g_{yd} &= \frac{y_d}{r_d} g_1 + y_d w^2 \frac{\phi}{r_d} - 2 w_v v_{dy} \\
    g_{zd} &= \frac{z_d}{r_d} g_1 - g_2
\end{align*}
\]

In the above expression equations, \( g_1 = -\frac{u}{r_d} \left[ 1 + \frac{\phi (2z)}{r_d} (1 - 5 \sin^2 \phi) \right] \), \( g_2 = -\frac{2u}{r_d} \left( \frac{\phi}{r_d} \right)^2 \sin \phi \), \( r_d = \sqrt{x_d^2 + y_d^2 + z_d^2} \), \( \phi = \sin^{-1}(z_d/r_d) \).

4. Calculation Model of Impact Point Prediction Based on Statistics

The calculation model of impact point prediction based on statistical analysis is designed to conduct a quantitative statistical analysis of the corrected parameters of errors in the constructed model by using a large number of measured data collected from historical missions and then complete the back calculation of the corrected compensating parameters, so as to correcting the calculation errors of the impact points.

Combined with the results of impact point error analysis in Section 2.4, the built model mainly deals with the first three errors. The fourth error will be eliminated by reducing the calculation step size and using Runge-Kutta algorithm. Error one and Error two are unified into debris separation trajectory information error. Therefore, two unknown error corrections will be designed in the model, and then according to the least square linear fitting theory, a reverse calculation will be carried out on the measured data collected from multiple missions to determine the two unknown error corrections, so as to realize the accurate calculation function of the new calculation model.

4.1 Model Design

Taking the key calculation method as the base, a correction (\( \Delta V \)) is added to the initial trajectory to compensate the error between the calculated velocity and the velocity in actual motion. A correction (\( \Delta K \)) is added to the comprehensive resistance coefficient in the atmospheric block acceleration to adjust the relationship between the model calculated results and the actual air resistance, so as to achieve more accurate air resistance correction. According to the principles of object motion, both of the corrections have a certain range. The two unknown corrections are added into the calculation model of impact points, i.e. the model established in this paper. The details are as follows:

a. Calculation of Debris Separation Information

Suppose that the velocity and position information of debris separation calculated by the model formula (3) are: \( V_0 = (v_{x0} \ v_{y0} \ v_{z0}) \), \( P_0 = (x_0 \ y_0 \ z_0) \) respectively. After adding the compensating correction (\( \Delta V \)), the separation information (only the speed compensation is corrected, but the position compensation is not corrected in accordance with the separation characteristics) is shown as follows:

\[
\begin{align*}
    V_d &= (v_{xd} \ v_{yd} \ v_{zd}) \\
    P_d &= (x_d \ y_d \ z_d)
\end{align*}
\]

\( v_{xd} = \left( \sqrt{v_{x0}^2 + v_{y0}^2 + v_{z0}^2} - \Delta V \right) * v_{x0}/\sqrt{v_{x0}^2 + v_{y0}^2 + v_{z0}^2} \),

\( v_{yd} = \left( \sqrt{v_{x0}^2 + v_{y0}^2 + v_{z0}^2} - \Delta V \right) * v_{y0}/\sqrt{v_{x0}^2 + v_{y0}^2 + v_{z0}^2} \).
\[ v_{zd} = \left( \sqrt{vx_0^2 + vy_0^2 + vz_0^2} - \Delta V \right) \ast \frac{vz_0}{\sqrt{vx_0^2 + vy_0^2 + vz_0^2}}; \]

\[ x_d = x_0; \ y_d = y_0; \ z_d = z_0. \]

b. Compensating Calculation of Atmospheric Block

The idea is to place the compensating coefficient \( \Delta K \) into the formula (6) to form the atmospheric block calculation model with compensating coefficient.

\[
\begin{align*}
g_{bx} &= -(k + \Delta K) vz_10^{-1}d_kv \\
g_{by} &= -(k + \Delta K) vy_10^{-1}d_kv \\
g_{bz} &= -(k + \Delta K) vz_10^{-1}d_kv
\end{align*}
\]

(11)

c. Acceleration Model for the Unpowered Falling Process

In the process of unpowered debris falling, the acceleration of the debris motion consists of two parts: gravitational acceleration and atmospheric block acceleration. Therefore, the acceleration model of debris unpowered falling can be obtained by the formula (7) and the formula (11):

\[
\begin{align*}
g_x &= (g_{xx}, g_{xy}, g_{xz}) \\
g_{xx} &= g_{xd} + g_{bx} \\
g_{xy} &= g_{yd} + g_{by} \\
g_{xz} &= g_{zd} + g_{bz}
\end{align*}
\]

(12)

d. Numerical Iterative Calculation Method of Impact Points

With regard to the calculation of the falling trajectory and impact points of the debris, according to the principles of object kinematics, under the condition that the acceleration is calculable, the velocity and position of the next moment can be calculated when the initial motion velocity and position of the object are known. In the integral iterative calculation, the step size of time should not be too large, generally no more than 10 ms. In the actual calculation, the smaller the step size is, the more accurate the iterative calculation is. But at the same time, the resources needed for the calculation also increase exponentially with the decrease of step size. So in practical application, the step size should be determined by a combination of calculation needs and computer operation speed (5 ms is taken for simulation calculation here). The iterative calculation formula is shown in formula (13). The value range of \( \Delta V \) and \( \Delta K \) is set in line with the influence of separation force at various levels and historical experience, and the step size is 0.24 and 0.02 respectively.

\[
\begin{align*}
v_{x(n+1)} &= v_{x(n)} + t \ast g_{xx} \\
v_{y(n+1)} &= v_{y(n)} + t \ast g_{xy} \\
v_{z(n+1)} &= v_{z(n)} + t \ast g_{xz} \\
x_{(n+1)} &= x_{(n)} + t \ast v_{x(n)} + 0.5 \ast g_{xx} \ast t^2 \\
y_{(n+1)} &= y_{(n)} + t \ast v_{y(n)} + 0.5 \ast g_{xy} \ast t^2 \\
z_{(n+1)} &= z_{(n)} + t \ast v_{z(n)} + 0.5 \ast g_{xz} \ast t^2
\end{align*}
\]

(13)

4.2 Calculation of Compensating Parameters of Impact Points

The calculation of debris impact point compensating parameters is mainly based on the trajectories of 25 historical missions, the time of separation points and the measured locations of debris. In the traversal calculation, the air resistance compensating coefficients and comprehensive velocity compensating domain values are set as a certain interval, which are processed in the form of 50 equal parts. The extraction process of the optimal compensating combination is illustrated by a group of data. In the three-dimensional diagram, X-axis represents air resistance compensating coefficients; Y-axis represents comprehensive velocity compensations at separation points; and Z-axis represents deviation between calculated results and measured results of impact points. It can be shown from the diagram that the minimum deviation is composed of a series of points (results), indicating that the accuracy of impact point calculation can be improved when multiple sets of compensating values are calculated using the impact point model.
By reducing the dimension of the statistical results, the optimal compensating combination of a certain mission is finally generated. Through the statistical fitting calculation of the optimal compensating combination of 25 samples, the velocity corrections and atmospheric block compensating coefficients required in this paper are also obtained.

5. Effect Verification of Real-time Impact Point Prediction
The verification of the impact point prediction is carried out by using the accurate impact point calculation system. The data source is the measurement data file of each mission. The data is obtained by reading the file. The calculation process is consistent with the real-time calculation process. The actual data of 25 samples are collected in the calculation of the debris. In order to further illustrate the effects of the calculation method model used in this paper, the calculation results of the present model are compared with those of the previous model. In this paper, the histogram is used to compare the errors of the results of each model. As shown in the histogram, it is obvious that the error between the calculated results of the present model and the measured values of the debris is the smallest.

By comparing the calculation results of different models based on geographical locations, each calculation result is normalized. It can be clearly seen from the diagram above that the calculation results of the model in this paper are more convergent and closer to each other relative to the measured impact points.
Figure 4. Normalized Results of Impact Points of Three Models

Taken together, through the comparison of the calculation results of three models, the calculation accuracy of the parabolic model is 53.69 km, and the calculation accuracy of the current impact point model is 16.63 km, while the calculation accuracy of the model proposed in this paper is 4.61 km. This indicates that the calculation accuracy of the debris impact points has been further improved.

6. Summary

In this paper, according to the actual requirements of space launch for the safety of landing area, the prediction process of heavy debris impact points is designed, and the basic algorithm of debris impact point calculation is studied. Through the analysis of the error sources of the impact point prediction, the research direction of improving the accuracy of the impact point prediction is defined. And on this basis, this study borrows the concept of big data comprehensive analysis, in light of the status of the base equipment, and makes full use of the valuable measured data resources of the base’s space launch. Further, the measured flight and landing area data information of multiple samples in Xichang launch site are also used. This study then employs statistical methods to make back calculations of the air resistance and velocity corrections affecting the impact point calculation. In doing so, a calculation model of real-time impact point prediction based on statistical principles is formed. What’s more, the functions of real-time impact point calculation system with high accuracy have been designed and carried out. Through the previous data verification, it shows that the calculation accuracy of the new model has been greatly improved compared with the original model. After the new model is put into use, it will provide fast and accurate information support for the safety analysis and demonstration of landing areas, real-time impact point calculation and debris search in landing areas for the follow-up launch samples.

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