Simulation Research on Nose Cone Shedding Trajectory of Terminal Guided Projectile

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Abstract. The falling off of nose cone during the flight of terminal guidance projectile may cause casualties and property losses, but the nose cone trajectory has not been noticed. In this paper, the differential equations of particle motion for terminal guided projectile are established by using the methods of external ballistic and theoretical mechanics. Three ballistic coefficients corresponding to firing distance, flight time and ballistic height are obtained by solving the ballistic equation in reverse. According to the time from launching to the nose cone and the ballistic coefficient, the initial state of the nose cone is calculated, and then according to the resistance coefficient and the mechanical equations of the nose cone, the trajectory of the nose cone is obtained by simulation, which provides scientific guidance for setting the safe area accurately.

1. Introduction

The nose cone, which is used to protect the guidance equipment at its initial stage of flight, is an important part of it and will fall off automatically at a certain time. With the increasing use of terminal guided projectiles, nose cones falling to the ground at high speed, result in casualties and property losses from time to time. At present, although a certain range of abscission is given, it is too large to be applicable. In this paper, a simple and accurate method for simulating the reaching area of the nose cone tribe is presented basing on the ballistic and mechanical theory.

2. Establishment of trajectory equation for terminal guided projectile and solution to fit trajectory coefficient

2.1. Establishing ballistic equation

The exterior ballistics of terminal guidance projectile-propelled rocket engine can be divided into uncontrolled flight phase, extended range phase, uncontrolled flight phase, inertial guidance phase and proportional navigation phase[1]. Because of the complication of each trajectory and, for the convenience of calculation, the terminal guidance projectile is regarded as the particle, which is equivalent to the grenade trajectory to establish its centroid motion differential equations. The simplified schematic diagram of centroid motion is shown in figure 1, and its equations of motion, such as formula (1):

\[ \frac{d^2 \mathbf{r}}{dt^2} = -\frac{gm}{\sqrt{\mathbf{r} \cdot \mathbf{r}}} \]
The symbolic meaning of formula (1) is in general ballistics textbooks.

2.2. Solving fit trajectory coefficient
According to the firing table data, the differential equations are solved with the firing distance, initial velocity, firing angle and altitude of a certain charge as known conditions. The fit ballistic coefficient \( C_1 \) of the corresponding firing distance, the fit ballistic coefficient \( C_2 \) of the corresponding projectile flight time and the fit ballistic coefficient \( C_3 \) of the corresponding ballistic height are obtained.

3. Simulation model for nose cone trajectory of terminal guided projectile

3.1. Force and motion analysis of nose cone
After a period of flight, the sensor of the terminal guided projectile generates a signal to ignite the pyrotechnic grain in the nose cone, increase the pressure in the chamber of the nose cone, break the broken screw, make the nose cone move forward relative to the seeker, separate from the seeker, and then make a parabolic motion. In most cases, when the terminal guided projectile works in the far area, the nose cone is thrown down in the trajectory descent stage. Therefore, taking the trajectory descent stage as an example, the force analysis is carried out, as shown in figure 2.

The acceleration of the nose cone is decomposed into two directions: direction of launch and that perpendicular to launch. The acceleration variation of nose cone is shown in figure 3.
Figure 2. Motion and force diagram of nose cone in the trajectory descent stage.

Figure 3. Schematic diagram of acceleration variation of nose cone in trajectory descent stage.

3.2. The method for calculating the location of the nose cone falling off (as the initial state)
The time T (seconds) from the firing to the nose cone is calculated as follows:

\[ T = 0.2 \times N + 11 \]  

(2)

Formula: N is the program setting time of firing initial data[2].

According to the time T and the above ballistic coefficients \( C_1, C_2 \) and \( C_3 \), solving equations (1), the states of the terminal guidance projectile under three conditions at T-moment is obtained: motion velocity, ballistic inclination, flight altitude and flight distance.

3.3. Method for obtaining landing location of nose cone

3.3.1. Calculation of drag coefficient of nose cone. The motion of nose cone can be regarded as particle trajectory. If the drag coefficient or ballistic coefficient is obtained, the landing position can be determined by particle trajectory equation. The drag coefficient method is adopted in this paper. According to reference[3], the resistance coefficient of nose cone can be replaced by Table 1.

| range of Mach numbers | \( C_{D0}(M_d) \) | range of Mach numbers | \( C_{D0}(M_d) \) |
|------------------------|------------------|------------------------|------------------|
| \( 0.1 < M_d < 0.2 \) | 0.850            | \( 1.0 < M_d < 1.1 \) | 1.385            |
| \( 0.2 < M_d < 0.4 \) | 0.860            | \( 1.1 < M_d < 1.2 \) | 1.415            |
| \( 0.4 < M_d < 0.6 \) | 0.900            | \( 1.2 < M_d < 1.3 \) | 1.420            |
| \( 0.6 < M_d < 0.8 \) | 1.100            | \( 1.3 < M_d < 1.4 \) | 1.400            |
| \( 0.8 < M_d < 0.9 \) | 1.250            | \( 1.4 < M_d < 2.8 \) | 1.290            |
| \( 0.9 < M_d < 1.0 \) | 1.330            | \( 2.8 < M_d < 5.6 \) | 1.150            |
3.3.2. Establishment of particle trajectory equation for nose cone. The nose cone is an irregular cone, with known weight, length, minimum and maximum diameter. The characteristic area can be approximately replaced by the minimum cross section, the maximum cross section and the average area of longitudinal section, that is:

\[ S = \frac{1}{3} \left( \pi \times \left( \frac{d_1}{2} \right)^2 + \pi \times \left( \frac{d_2}{2} \right)^2 + \frac{1}{2} \times \pi \times \left( \frac{d_1}{2} \right)^2 + \frac{1}{2} \times (d_1+d_2) \times l \right) \]

It can be regarded as a known condition. (Specific data is not public information)

Because of \( R_x = \rho \frac{v^2 SC_x(M_a)}{2} \), there is: \( a_x = R_x / m = \rho \frac{v^2 SC_x(M_a)}{2m} \)

And because of the air density function \( H(y) = \rho / \rho_0 = \tau_{0a} \frac{\pi(y)}{\tau(y)} \), \( \rho_0 = 1.206 \text{ kg/m}^3 \) and \( \tau_{0a} = 288.9 \text{ k} \), there is:

\[ a_x = \frac{174.2067 \times 6.84 \times 10^{-3}}{0.75} \frac{v^2 C_x(M_a) \pi(y)}{\tau(y)} = 1.59 \frac{v^2 C_x(M_a) \pi(y)}{\tau(y)} \]

So the motion equation of nose cone in trajectory descent stage is:

\[
\begin{align*}
\frac{du}{dt} &= -1.59 C_x(M_a) \frac{\pi(y)}{\tau(y)}uv \\
\frac{dw}{dt} &= 1.59 C_x(M_a) \frac{\pi(y)}{\tau(y)}wv - g \\
\frac{dy}{dt} &= w \\
\frac{dx}{dt} &= u \\
v &= \sqrt{u^2 + w^2}
\end{align*}
\]

(3)

According to the initial velocity, ballistic inclination, flight altitude and flight distance of the nose cone obtained from 3.2 and the drag coefficient in 3.3.1 solution equations (3), the simulation calculation model of the nose cone trajectory can be obtained.

4. Simulation and calculation of landing trajectory of nose cone of terminal guided projectile

According to the trajectory simulation model of nose cone, the corresponding software for calculation is written with C++. Table 2 shows the deviation between the actual landing point of the nose cone of eight terminal guidance projectiles measured during firing practice and the landing point obtained from the simulation calculation model using the nose cone trajectory. The minimum deviation of 16.2 meters and the maximum deviation of 55.4 meters show that the position of the nose cone calculated by this method is "quite" accurate.

| Impact point of measurement data | Software calculation results | Deviation |
|---------------------------------|-------------------------------|-----------|
| (39151, 78739)                  | (39112, 78711)               | 48.0      |
| (39383, 78902)                  | (39397, 78920)               | 22.8      |
| (44389, 89600)                  | (44404, 89594)               | 16.2      |
| (44266, 89525)                  | (44273, 89542)               | 18.4      |
| (44485, 89649)                  | (44502, 89677)               | 32.8      |
| (43877, 81388)                  | (43905, 81410)               | 35.6      |
| (43974, 81553)                  | (43993, 81604)               | 55.4      |
| (43433, 81198)                  | (43480, 81225)               | 54.2      |
5. Conclusion
Through many experiments and simulation validation, the accuracy of nose cone landing position calculated by this simulation can fully satisfy the application of projectile firing safety prediction. The simulation calculation method can simulate the nose cone trajectory of the terminal guidance projectile accurately and quickly, and can calculate the impact point of the trajectory.

References
[1] Zeng, F.P., Ye, Z.H. (2011) 152 millimeter laser terminal guided projectile weapon system and operation course. Chinese People's Liberation Army Publishing House. Beijing.
[2] Liu, Y.X., Liu, Y.W. (2009) Application of artillery precision guided weapon system. Artillery University of Nanjing branch. Nanjing.
[3] AD350496-L (US Defense Report)
[4] Garnell, P. (2003) Guided Weapon Control Systems. Beijing Institute of Technology. Beijing.