Influencing Factors of the Initiation Point in the Parachute-Bomb Dynamic Detonation System

Li Qizhong¹,², Wang Ye²*, Wang Zhongqi¹ Bai Chunhua¹
¹Beijing Institute of Technology, Beijing, China.
²North China Institute of Science and Technology, East Beijing, China

*Corresponding author’s E-mail: wangye_0422@126.com

Abstract: The parachute system has been widely applied in modern armament design, especially for the fuel-air explosives. Because detonation of fuel-air explosives occurs during flight, it is necessary to investigate the influences of the initiation point to ensure successful dynamic detonation. In fact, the initiating position exist the falling area in the fuels, due to the error of influencing factors. In this paper, the major influencing factors of initiation point were explored with airdrop and the regularity between initiation point area and factors were obtained. Based on the regularity, the volume equation of initiation point area was established to predict the range of initiation point in the fuel. The analysis results showed that the initiation point appeared area, scattered on account of the error of attitude angle, secondary initiation charge velocity, and delay time. The attitude angle was the major influencing factors on a horizontal axis. On the contrary, secondary initiation charge velocity and delay time were the major influencing factors on a horizontal axis. Overall, the geometries of initiation point area were sector coupled with the errors of the attitude angle, secondary initiation charge velocity, and delay time.

1. Introduction

The parachute system is widely used nowadays in various fields, such as goods transportation and rapid deployment of war fighters, equipment and supplies. The armament design is important in fuel-air explosives (FAE). The FAE system is composed of buste charge, fuel, canister, secondary initiation charge, and parachute. The secondary initiation charge is set on the top of parachute in the FAE system. A process is called dynamic detonation when the detonation of fuel-air explosives occurs during flight. A successful dynamic detonation depends on the initiated position of secondary initiation charge. If the position of the charge initiating is in the cloud, dynamic detonation is successful; otherwise, dynamic detonation fails. Therefore, the influencing factors of initiation point is becoming an important issue.

In the dynamic detonation system design, there is only a coordinate of initiation point. When the factors have errors in the experiment in case of reality condition, for example, error caused by devices or random error, the accuracy of initiation point decrease. Therefore, the initiation point area is produced.

According to the characteristics of dynamic detonation, the parachute-bomb system trajectory is divided into three phase: extraction phase, falling stability phase, and secondary initiating phase. Previous studies mostly focused on the changing flight signatures of parachute-bomb system in the extraction phase²⁴ and landing point in the falling stability phase⁵⁻⁷. Related results were obtained by
theoretical analysis\textsuperscript{8-11} and numerical simulation\textsuperscript{12-15}. However, the parachute-non-bomb phase was seldom studied. Though a series of airdrop tests, the major influencing factors of initiation point and the regularity were obtained. Based on the regularity, the volume equation of initiation point area was established to predict the range of initiation position in the fuels.

2. Experiment apparatus and procedures

2.1. General

The airdrop experiments were carried out with hot air balloon system. As shown in Fig. 1, the parachute-bomb system was lifted 300 m above the ground with the hot air balloon system. Two high-speed digital cameras were placed on the ground. When the wind speed was less than 5 m·s\textsuperscript{-1}, the throwing system was triggered and the parachute system began to drop. At the same time, the experimental process was photographed with two high speed digital cameras. The parachute-bomb system is composed of buster charge, fuel, canister, secondary initiation charge, and parachute, as shown in Fig. 2.

The data of the dropping process were acquired with two V12 high-speed color photography systems. The photographing frequency was 1000 frames per second. The secondary initiation charge trajectory of dynamic detonation system was obtained by image processing technology. In order to ensure the synchronism of the data recording, primary initiation time was considered as zero time. The coordinate system was established with the swept area of parachute system and the ground projective point of the parachute center was considered as the origin point. The typical result of secondary initiation charge trajectory is shown in Fig. 3.

![Sketch of the experimental layout](image1)

![Photo of experimental layout](image2)

\textbf{Fig. 1} Experimental layout
2.2. Trajectory of secondary initiation charge
As shown in Fig. 3, the secondary initiation charge trajectory tends to be a straight line. Thus, the secondary initiation charge appeared to be like uniform motion. According to the experiment, influencing factors of secondary initiation charge trajectory included the attitude angle, parachute-non-bomb velocity, and delay time.

3. Results and discussion

3.1 Influence of attitude angle on the initiation point
These factors influenced the attitude angle, for example, wind power, wind speed, type of parachute, and the length of parachute rope, and so on. When the attitude angle changed, the initiation point was different with the predict point.

In order to find the rule between attitude angle with initiation points, points of trajectory under same delay time (0.2 s) and velocity (32.20m/s) were picked to drawn in Fig. 4. As Fig. 4 shown, the shape of inanition point area is curve of trigonometric function under attitude angle. The attitude angle had obvious influence on horizontal axis(X axis), and little effect on vertical axis(Y axis).

In a word, the attitude angle is the major influences on horizontal axis. The initiation points area changed significantly with the attitude angle on horizontal axis. The point in Fig.3 is fitted on the purpose of finding the influence rules. The relation formulae is expressed as

![Fig. 2 Scheme of the Parachute-bomb system](image1)

![Fig. 3 Secondary initiation charge trajectory](image2)
\[
\begin{align*}
    x &= a \sin \theta \\
    y &= b \cos \theta
\end{align*}
\]

Where $a$, $b$ are constants and have relationship with delay time and velocity of secondary initiation charge; $x$, $y$ are the coordinate of X, Y axis about initiation point, respectively.

3.2 Influence of velocity of secondary initiation charge on the initiation point

The changes of velocity of secondary initiation charge were caused by these factors, for example, parachute formation (deformation or satiation), the resistance of fuel dispersal, and the gravity, and so on. When the velocity changed, the initiation point was different with the predict point.

In order to find the dispersion rule between velocities of secondary initiation charge with initiation points, points of trajectory under same delay time (0.2 s) and the attitude angle (0°) were picked to draw in Fig. 5. As Fig. 5 shown, the shape of inanition point dispersion is a straight line under the velocities. The velocity of secondary initiation charge had obvious influence on vertical axis, and no effect on horizontal axis.

In brief, the velocity of secondary initiation charge is the major influences on vertical axis. The initiation point’s area changed significantly with the velocity on horizontal axis. The point in Fig. 5 is fitted on the purpose of finding the influence rules. The relation formulae is expressed as

\[
\begin{align*}
    x &= c \cdot v \\
    y &= d \cdot v
\end{align*}
\]

Where $c$, $d$ are constants and have relationship with delay time and the attitude angle; $x$, $y$ are the coordinate of X, Y axis about initiation point, respectively.

3.3 Influence of delay time on the initiation point

These factors influenced the delay time, for example, initiation charge reliability,
electromagnetic interference, and ground conditions (flat, hard, wet or low-lying), and so on. When the delay time changed, the initiation point was different with the predict point.

In order to find the rule between delay time with initiation points, points of trajectory under same attitude angle (0°) and velocity (32.20m/s) were picked to drawn in a Fig. 6. As Fig. 6 shown, the shape of initiation point area is a straight line under delay time. The delay time had obvious influence on vertical axis, and no effect on horizontal axis.

In short, the delay time is the major influences on vertical axis. The initiation point area changed significantly with the delay time on vertical axis. The point in Fig. 6 is fitted on the purpose of finding the influence rules. The relation formulae is expressed as

\[
\begin{align*}
  x &= e \cdot t \\
  y &= f \cdot t
\end{align*}
\]

Where \( e, f \) are constants and have relationship with delay time and the attitude angle; \( x, y \) are the coordinate of X, Y axis about initiation point, respectively.

![Fig. 6 Area of initiation point caused by delay time](image)

### 3.4 Influence of composite factors on the initiation point

The initiation point dispersion under different delay time, velocity of velocity of secondary initiation charge and attitude angle was drawn in the Fig. 7. As the Fig. 7 shown, the shape of initiation point is sector. The volume of the dispersion sector could be estimated by math method, as shown in Fig. 8. The coordinates of serving points is as follows

\[
\begin{align*}
  A(x_A, y_A) &= \left(0, -v_{\text{min}} t_{\text{min}}\right) \\
  B(x_B, y_B) &= \left(v_{\text{min}} t_{\text{min}} \sin \theta_{\text{max}}, -v_{\text{min}} t_{\text{min}} \cos \theta_{\text{max}}\right) \\
  C(x_C, y_C) &= \left(v_{\text{max}} t_{\text{max}} \sin \theta_{\text{max}}, -v_{\text{max}} t_{\text{max}} \cos \theta_{\text{max}}\right) \\
  D(x_D, y_D) &= \left(0, -v_{\text{max}} t_{\text{max}}\right)
\end{align*}
\]
Where $x$ and $y$ respectively represent the horizontal and vertical distances between the final point and the origin point, viz., A,B,C,D; $v$ denotes the velocity of secondary initiation charge, $\theta$ represents the attitude angle and $t$ is delay time.

And the expression formula of key line can be represented by

$$
\begin{align*}
L_{AB}(y) : x &= \sqrt{(vt)^2_{\text{min}} - y^2} \\
L_{CD}(y) : x &= \sqrt{(vt)^2_{\text{max}} - y^2}
\end{align*}
$$

(2)

Where $v_{\text{max}}$, $v_{\text{min}}$ respectively represent maximum and minimum of velocity; $t_{\text{max}}$, $t_{\text{min}}$ respectively represent maximum and minimum of delay time.

In addition, the expression of the partition volume

$$
\begin{align*}
V_{AB} &= \pi \int_{y_a}^{y_b} [L_{AB}(y)]^2 dy \\
V_{BC} &= \pi (y_b - y_c)(x_a^2 + x_b^2 + x_b x_c) / 3 \\
V_{CD} &= \pi \int_{y_c}^{y_d} [L_{CD}(y)]^2 dy
\end{align*}
$$

(3)

In conclusion, with Eq. (1)-(3), the volume of initiation point dispersion is expressed as

$$
V_{\text{point}} = \pi \int_{y_a}^{y_c} [\sqrt{(vt)^2_{\text{max}} - y^2}] dy + \pi (y_b - y_c)(x_a^2 + x_b^2 + x_b x_c) / 3 - \pi \int_{y_c}^{y_d} [\sqrt{(vt)^2_{\text{min}} - y^2}] dy
$$

Where $\theta_{\text{max}}$ and $\theta_{\text{min}}$ respectively represent maximum and minimum of attitude angle in the error range; $t_{\text{max}}$, $t_{\text{min}}$ respectively represent maximum and minimum of delay time in the error range; $v_{\text{max}}$ and $v_{\text{min}}$ respectively represent maximum and minimum of velocity in the error range.

![Fig. 8 Sketch of initiation point area](image)

4. Conclusion
In the paper, we studied the influencing factors of the initiation point dispersion in the fuel-air explosives. The main conclusions can be summarized as follows:

The attitude angle is the major influences on horizontal axis. The dispersion relationship can be represented by
\[
\begin{align*}
  x &= a \sin \theta \\
  y &= b \cos \theta
\end{align*}
\]

The delay time and the velocity of secondary initiation charge are the major influences on vertical axis. The dispersion relationship are given by
\[
\begin{align*}
  x &= c \cdot v \\
  y &= d \cdot v
\end{align*}
\]
and
\[
\begin{align*}
  x &= e \cdot t \\
  y &= f \cdot t
\end{align*}
\]
respectively.

The volume of initiation point dispersion can be obtained by the errors of attitude angle, delay time, and the velocity of secondary initiation charge. The volume can be calculated, that provided reference on the reliability of dynamic detonation system and parachute-bomb design. The expression of the volume is
\[
V_{\text{point}} = \pi \int_{y_p}^{y_d} \left[ \sqrt{\left( \frac{v(\theta)_{\text{max}}}{2} - y^2 \right)^2 - x^2} \right] \, dy + \pi (y_h - y_c)(x_h^2 + x_p^2 + x_h x_p) / 3 - \pi \int_{y_p}^{y_d} \left[ \sqrt{\left( \frac{v(\theta)_{\text{max}}}{2} - y^2 \right)^2} \right] \, dy.
\]

Acknowledgements
A lot of thanks to the fundamental research funds for the Central Universities Fund (3142017066).

References:

[1] Bai Chunhua, Liang Huimin, Li Jiangping. Cloud detonation. 1st ed. Beijing: Science Press; 2012.p.140-144.

[2] Bai CH, L JP. Bomb Rear Flow Field Numerical Simulation and Flexible Cabin opening Reliability analysis. Transactions of Beijing Institute of Technology, 2005; 25(7): 585-589[In Chinese].

[3] Pei YX, Liu QM, Bai CH, Calculation and Simulation of Mother-Child Aeronautic Fuel Air Explosive Bombs Dispersion of Bomb’s Point of Fall. Transactions of Beijing Institute of Technology, 2002;22(5): 622-625[In Chinese].

[4] KE P, YANG C Y A X. Extraction Phase Simulation of Cargo Airdrop System[J]. Chinese Journal of Aeronautics,2006(No.4):315-321.

[5] Z Biqiang, J Chunlan, W Zaicheng, X Heng, Y Weiling. Research on the Ballistic Fall Point Spread of the Parachute-bomb System. Journal of Projectiles. Rockets, Missiles and Guidance, 2010;30(1): 105-108[In Chinese].

[6] Pan C, Guo Y. Design and simulation of ex-range gliding wing of high altitude air-launched autonomous underwater vehicles based on SIMULINK[J]. Chinese Journal of Aeronautics, 2013(No.2):319-325.

[7] Vladimir N, Dobrokhodov O A Y A. Six-Degree-of-Freedom Model of a Controlled Circular Parachute. JOURNAL OF AIRCRAFT, 2003,40(3):482-493.

[8] Ginn J M, Z R D B. Parachute Dynamic Stability and the Effects of Apparent Inertia[J]. American Institute of Aeronautics and Astronautics, 2014.

[9] Fan Y, Xia J. Simulation of 3D parachute fluid–structure interaction based on nonlinear finite element method and preconditioning finite volume method[J]. Chinese Journal of Aeronautics, 2014(No.6):1373-1383.

[10] Chen Jie, Shi Zhongke. Aircraft Modeling and Simulation with Cargo Moving Inside[J]. Chinese Journal of Aeronautics,2009(No.2):191-197.

[11] Ginn J M, Z R D B. Parachute Dynamic Stability and the Effects of Apparent Inertia. American Institute of Aeronautics and Astronautics, 2014.

[12] CHENG H, ZHANG X, YU L, et al. Study of velocity effects on parachute inflation performance based on fluid-structure interaction method[J]. Applied Mathematics, 2014.
[13] CHEN Xiaopenga, GUAN Huanwenb, ZHUO Congshanc, et al. Physical Body Impact After High Altitude Bail-out [J]. Chinese Journal of Aeronautics, 2011(No.2):145-149.

[14] WANG Si-guo, TANG Geng-sheng, YANG Hui, et al. Orthogonal projection method for rotator's spatial sweep angle and rotating speed measurement [J]. Journal of Experiments in Fluid Mechanics, 2010, 24(1):79-83.

[15] CHENG H, ZHANG X, YU L, et al. Study of velocity effects on parachute inflation performance based on fluid-structure interaction method [J]. Applied Mathematics, 2014.

[16] Bai CH, Wang Y, Li JP. Influencing factors of parachute-non-bomb trajectory in the fuel-air explosives.