Establishment and analysis of damage calculation model under fuel air explosion effect

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Abstract. Fuel air explosive has unique damage characteristics because of its different action mechanism. In this paper, through analyzing the damage mechanism and characteristics of fuel air explosive, the damage efficiency of fuel air explosive was quantitatively described by using overpressure and specific impulse. In combination with theoretical calculation and experimental fitting, the corresponding damage effectiveness calculation model of fuel air explosive was established. According to the actual application of fuel air explosive, the group of personnel was selected as the pseudomorphic target, the distribution area and relevant parameters of the target were set, so as to establish the corresponding damage criteria, which provided a reference for the effective evaluation of the damage efficiency of fuel air explosive.

1. Introduction

Fuel air explosive is a multi-purpose, high-efficiency modern combat surface damage ammunition, which damages targets by fuel air explosive effect\cite{1-2}. When the fuel air explosive reaches a certain height above the target, the warhead equipped with fuel air explosive agent and timing initiation device is detonated at the right time.

In the process of scattering, the fuel quickly diffuses into the mist droplets and mixes with the air to form the volatile gas. Fuel clouds are formed by suspension of liquid or solid particles. The aerosol explodes in an instant, producing a powerful shock wave overpressure. So the fuel air explosion effect is even more powerful. Its power is equivalent to the explosive power of TNT 5 ~ 10 times \cite{3}. Compared with conventional hard kill ammunition, it has a large damage area and a better damage effect without direct hit to the target \cite{4}. Not only can it strike a cluster of military targets directly and effectively on the ground and at sea, but it can also flood into bunkers, trenches and underground structures to kill enemy forces, while destroying weapons and electronics that are unprotected or only soft-protected\cite{5}.

The damage mechanism of fuel air explosion effect on the target is basically the same as that of conventional explosive blast shock wave, but the fuel air explosion effect lasts longer. The vulnerability of effective forces to the fuel air explosion effect is mainly determined by the amplitude and duration of the associated peak overpressure and instantaneous wind pressure at the time of explosion, which can be divided into three stages\cite{7}.
The damage caused by initial fuel air explosion effect in the first stage is directly related to the peak overpressure of shock wave front. The shock wave is accompanied by a sharp burst of pressure that damages the vital central nervous system through compression, jarring the heart and other organs[5]. In general, living forces, especially organs filled with air, are more vulnerable to damage, which is known as overpressure damage, and can also destroy weapons and electronic equipment that are unprotected or only soft-protected. In the second stage, the cloud burst effect refers to the destruction of the target by the flying object driven by the explosion wave. In the third stage, the fuel air explosion effect is caused by the overall displacement of the target caused by the translational force generated by the shock wave and explosive wind dynamic pressure[1-3].

When multiple fuel air explosives explode near the target, there is a cumulative superposition effect of shock wave, which greatly increases the damage ability of the target. However, the research on this problem is not deep enough at present. Therefore, this paper mainly considers the overpressure influence and specific impulse of fuel air explosion effect.

2. Peak overpressure and specific impulse of shock wave

In the evaluation of the effectiveness of the fuel air explosive, the overpressure distribution of the shock wave formed after the explosion should be known. There are two commonly used methods: one is theoretical calculation; the second is experimental fitting[8-9].

2.1. Theoretical overpressure calculation

The peak overpressure and specific impulse of the air shock wave caused by the explosion of fuel air explosive outside the cloud can be estimated by the following two equations[10] (3r_c > r > r_c):

\[
\begin{align*}
    r_c &= 1.842m^{1/3} \\
    \Delta P_m &= \Delta P_{cj}(63.46e^{-2.443r} + 0.476e^{-0.4152r}) \\
    t_r &= 0.1882\Delta P_m m^{1/3}(e^{-0.08743r} + 2 \ln 0.6602r)
\end{align*}
\]

Where, \( r_c \) is the cloud radius and \( m \) is fuel charge mass(kg). \( \Delta P_m \) is the peak overpressure of air shock wave at \( r \) from the detonation center, and \( t_r \) is the specific impulse of fuel air explosion at \( r \). \( r \) is relative distance, \( r = r/m^{1/3}, m/\text{kg}^{1/3} \). \( \Delta P_{cj} \) is detonation overpressure, \( \Delta P_{cj} = P_{cj} - P_0 \). \( P_0 \) is the atmospheric pressure, 0.1013MPa, \( P_{cj} \) can be calculated by the following equation:

\[
\Delta P_{cj} = \frac{1}{1 + \kappa} \rho_0 D^2
\]

Where, \( \kappa \) is multiple exponent of detonation product. \( \rho_0 \) is density of fuel air explosive mixture(\text{kg/m}^3) and \( D \) is velocity of detonation (\text{m/s}).

2.2. Experimental fitting

When calculating the overpressure distribution of fuel air explosive detonation with the experimental fitting method, it is assumed that the overpressure distribution formed by the explosion of fuel air explosive detonation conforms to the similar law with the overpressure distribution formed by the explosion of conventional ammunition[8-9], and the form is as follows:

\[
\Delta P_m = K \left( \frac{r}{r_c} \right)^{1/2} \left( \frac{r}{r_c} \right)^{2/3} \left( \frac{r}{r_c} \right)^{3/2} + K \left( \frac{r}{r_c} \right)^{1/2} \left( \frac{r}{r_c} \right)^{2/3} \left( \frac{r}{r_c} \right)^{3/2}
\]

Where, \( \tilde{r} \) is relative distance, \( \tilde{r} = r/m^{1/3}, m/\text{kg}^{1/3} \). \( M \) is TNT equivalent of the fuel charge of a fuel air explosive (kg) while \( \Delta P_m \) is peak overpressure of air shock wave at \( r \) from detonation center. The
calculation formula of shock wave overpressure of a certain fuel air explosive is obtained by using the least square method:

\[ \Delta P_m = \frac{0.084}{r} + \frac{0.27}{r^2} + \frac{0.7}{r^3} \quad (1 \leq r < 10 \sim 15) \]  

(6)

3. Damage criterion

The targets of the fuel air explosive attack are mainly the personnel cluster targets. The target distribution area width is \( W_t \) (Vertical plane direction), the deep length is \( L_t \). The staff is evenly distributed internally. Specific distribution parameters of the target are as follows:

The personnel target is simplified into a rectangular cuboid. Its length, width and height are \( l_r \), \( w_r \), and \( h_r \). The depth interval is \( \Delta L_r \). The spaced width is about \( \Delta W_r \), as shown in Figure.1.

![Figure.1 Personnel target distribution diagram](image)

Then the surface density of personnel target \( \omega_r \) is:

\[ \omega_r = \frac{1}{\Delta L_t \Delta W_r} \]  

(7)

The number of persons in the target area \( N_r \) is:

\[ N_r = \frac{L_t W_t}{\Delta L_r \Delta W_r} \]  

(8)

The shock wave caused by the explosion of a fuel air explosive is destructive to many types of targets, such as personnel, fortifications, vehicles, etc. The damage process of shockwave to the target is very complicated. Currently, the commonly used damage criterion is shockwave overpressure criterion, which is as follows:

\[ P_t = \begin{cases} 1 & \Delta P_m \geq \Delta P_c \\ 0 & \Delta P_m < \Delta P_c \end{cases} \]  

(9)

Where, \( P_t \) is target damage probability; \( \Delta P_c \) is shock wave threshold for target damage. Usually, different targets have different thresholds.

4. Conclusion

Compared with conventional kill ordnance, the fuel air explosive has a large damage area and a better damage effect without direct hit to the target. In this paper, by analyzing the damage mechanism and characteristics of fuel air explosive, the damage efficiency of fuel air explosive is quantitatively described by using overpressure and specific impulse, and the corresponding calculation model of damage efficiency is established. According to the actual application of fuel air explosive, the
personnel cluster is selected as the pseudomorphic target, and the distribution area and related parameters of the target are set, so as to establish the corresponding damage criteria.

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