Research on Battlefield Repair of Tractors Damaged by Fragment Warhead

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Abstract: This study established a typical tractor model and divided the vehicle model into five parts. At the same time, combined with the damage model of the fragment warhead, the probability of damage to various parts of the vehicle when the fragment warhead explodes at different positions was analyzed. Based on the constructed model, we randomly generate 1000 bomb landing points to obtain the number of bomb fragments hitting different parts of the vehicle. Then we analyze the vulnerable parts in each part of the vehicle, and provide corresponding repair methods and spare parts carrying capacity for the corresponding parts. It has certain reference significance for the battlefield support of vehicle.

Keywords: Battlefield Repair; Fragment Warhead; Damaged

1. Introduction

Tractor is an important carrier for achieving various equipment mobility transfer. Damage to vehicles on the battlefield will inevitably affect equipment transfer and even delay the optimal combat timing. In order to quickly restore the mobility of the equipment and the combat effectiveness of the troops, the battlefield repair of vehicles is particularly crucial. During the combat process, a combination of emergency repair measures and replacement of spare parts is usually adopted. The uncertainty of vehicle damage during wartime also leads to uncertainty in the consumption of emergency tools and spare parts, and the carrying capacity of spare parts on vehicles has a certain limit. Therefore, how to scientifically and reasonably estimate the amount of spare parts carried by vehicles is the key to solving the battlefield repair problem.Hu used the Markov chain method to study the calculation problem of the probability of spare parts for combat damage repair [1]. Zhao used the entropy weight method to determine the quantity of spare parts by using location, criticality, and maintainability as indicators [2]. Yao proposed a demand prediction model using the Analytic Hierarchy Process model, taking into account aircraft combat damage rate and component vulnerability [3, 4]. Chen proposed a new damage probability model based on the safety evaluation method of ship shell loss zone [5, 6]. Although some scholars have studied the quantity of spare parts, they have not taken into account the particularity of bomb damage on the battlefield. This study established a typical tractor model, considering the damage model of fragment warhead. The damage situation of fragment warhead on different parts of vehicles was studied, and the priority of carrying spare parts and repair tools was analyzed based on the probability of damage in different parts. It has certain reference significance for the battlefield support of vehicle.

2. Model Establishment

Tractors are generally modified for medium-sized transport vehicles. Replace the position of the original carriage with equipment, while keeping other parts largely unchanged. Figure 1 shows a general medium-sized transport vehicle and its basic dimensions.

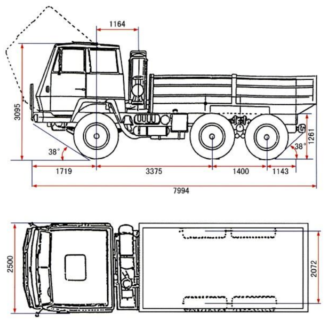

Figure 1. Schematic Diagram of Vehicle Dimensions

There are many electronic components in the head of a tractor, and their damage is complex, making it difficult to repair them in a short period of time. Electronic components are small in size and light in weight, and have a very small impact on the carrying capacity of spare parts in the vehicle. Therefore, the damage to the front part of the vehicle will not be considered. So this study only considers the damage to the chassis and the following parts of the tractor, so the tractor can be simplified into a rectangular model. For the convenience of studying the number of projectile fragments borne by each region, the model is divided into five equal parts along the direction from the front to the rear of the vehicle, numbered as A, B, C, D, and E, As shown in Figure 2.

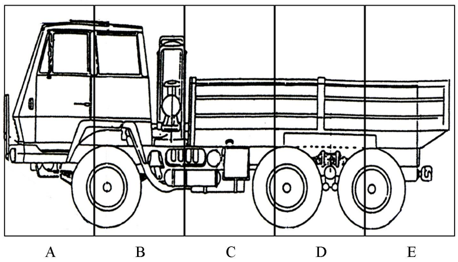

Figure 2. Diagram of Vehicle Model Partitioning

This study cites the research of Zhao Weiping et al [7, 8] and uses a cylindrical fragment warhead. The shell is made of AL7039, with a density of 2.77g/cm^3, a yield strength of 337 MPa, and a shear modulus of 2.76x10^4 MPa. The fragmentation material is Steel4340, with a density of 7.83g/cm^3, a yield strength of 792 MPa, and a shear modulus of 8.18x10^4 MPa. There are over 3000 fragments in this fragment warhead, and 3000 fragments are selected here. The initial velocity distribution of fragments is between 1500-3700 m/s. The killing area of the fragment warhead is approximately a hollow cone, with fragments evenly distributed along the circumference in the same plane [9-11]. Therefore, when fragments hit a vehicle, they can be approximated as uniformly distributed in a cylindrical shape.

3. Fragment Warhead Damaged Vehicles

The warhead will explode from all directions of the vehicle, and the fragments or shock waves of the explosion can cause damage to the vehicle. When the shell explodes at close range to the vehicle, the damage caused by the shock wave to the vehicle is fatal and generally cannot be repaired, so only the damage caused by fragments to the vehicle is studied. If the shell explodes in front of the vehicle, it will cause serious damage to the driver's cabin, mostly electronic components with minimal carrying capacity and almost no spare parts. If the shell explodes above the vehicle, some fragments penetrate the top skin of the front of the vehicle, damaging the electronic components of the cab, and some fragments hit the onboard equipment. There are very few key components behind the vehicle.

Therefore, when the warhead explodes on the side of the vehicle, it causes significant damage to the vehicle. This study will mainly analyze the number of fragments that hit different parts of the vehicle when the fragment warhead explodes at different positions on the side. Establish a Cartesian coordinate system by projecting the vertex of the front of the vehicle onto the ground as the coordinate origin, with the position from the front to the rear of the vehicle as the positive X-axis direction, the vertical side of the vehicle facing outward as the positive Y-axis direction, and the vertical upward as the positive Z-axis direction. The relative position between the shell and the vehicle is shown in Figure 3.

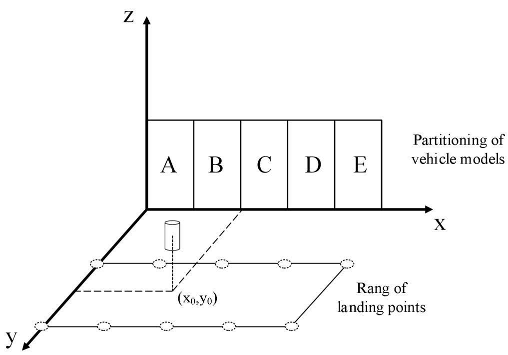

Figure 3. Fragment Warhead Relative to Vehicle Position

In general, when the fragment warhead approaches ground equipment, the detonation device executes the explosion command. Assuming that the shell causes the greatest damage to the vehicle, ensure that all fragments do not fly out of the vehicle model in the Z direction. In this way, it is only necessary to analysis the number of fragments that hit different parts of the vehicle model at different positions in the X and Y directions of the fragment warhead. Due to the fact that fragments can be approximated as uniformly distributed in a cylindrical shape when hitting a vehicle, the distribution density of fragments in space after the fragment warhead explodes is:

$$\rho = \frac{N}{2\pi l h} \tag{1}$$

Among them, N is the number of fragments after the explosion of the fragment warhead, l is the distance from the current fragment position to the center of the fragment warhead, and h is the diffusion height of the fragment warhead. From the equation, it can be seen that the distribution of fragment density varies with distance and diffusion height.

Assuming the coordinates of the warhead are (x_0, y_0), then when the fragment hits the vehicle, the distance between the fragment and the warhead is

$$l = \sqrt{(x - x_0)^2 + y_0^2} \tag{2}$$

The number of fragments that hit the vehicle model part A after the explosion of the fragment warhead is

$$N_A = \int_a^b \frac{N}{2\pi\sqrt{(x-x_0)^2 + y_0^2}} \times \frac{y_0}{\sqrt{(x-x_0)^2 + y_0^2}} dx \tag{3}$$

Among them, a and b are the two boundaries of part A in the x-direction, and $b > a$.

By following this method, the number of fragments in regions B, C, D, and E can be calculated sequentially.

There are two main situations where shells can cause damage to vehicles. One is when the explosive wave directly damages the vehicle. In this case, the damage to the vehicle is relatively complex and almost difficult to repair; Another approach is to damage the vehicle with flying debris, in which case the vehicle can continue to drive or undergo simple emergency repairs before proceeding. Due to the fact that the vehicle has almost no value for repair in the first scenario, this study mainly analyzes the second scenario. The shortest distance between the projectile and the vehicle model is 3 meters. Due to the randomness of the landing points of the shells, 5 landing points were set at a distance of 3 meters and 6 meters from the side of the vehicle, as shown in Figure 3.

When the warhead lands at a distance of 3 meters from the vehicle, that is, when the landing points of the warhead are (0, 3000), (2000, 3000), (4000, 3000), (6000, 3000), and (8000, 3000), the number of fragments that hit parts A, B, C, D, and E after the warhead explodes is shown in Figure 4. From the figure, it can be seen that when the coordinates of the warhead's landing point are symmetrical about the centerline of the vehicle's side, the number of fragments hitting the symmetrical area of the vehicle about the centerline is also equal. From the X-axis direction, the part corresponding to the landing point coordinates has the highest number of fragments hit, but the maximum number of fragments hit in each part is not significantly different, not exceeding 50.

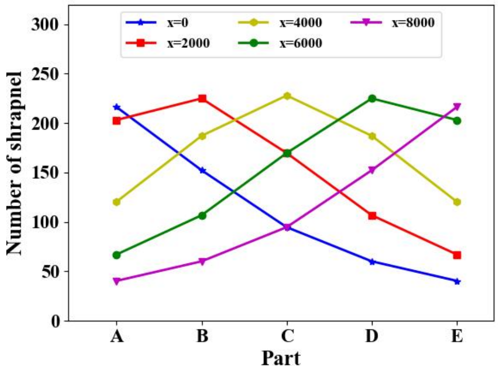

Figure 4. When y=3000, the Number of Fragments Hitting Each Part at Different X Values

When the warhead lands at a distance of 6 meters from the vehicle, i.e. when the projectile hits points of (0, 6000), (2000, 6000), (4000, 6000), (6000, 6000), and (8000, 6000), the number of fragments that hit parts A, B, C, D, and E after the projectile explodes is shown in Figure 5. Overall, when the shell is 3 meters and 6 meters away from the vehicle, the number of fragments hitting each part shows the same variation pattern. In terms of quantity, after the shell moves 3 meters away from the vehicle in the y-direction, the maximum number of fragments hitting each part significantly decreases, with a reduction of 70-100. However, the minimum number of fragments hitting each part did not decrease significantly, with a maximum reduction of 20. The above rules are in line with our understanding of vehicles damaged by fragment warheads, and can partly demonstrate the accuracy of the debris prediction model.

The landing point of the warhead has randomness. Therefore, 1000 landing points are randomly generated within the rectangular landing area with (0, 3000) and (8000, 6000) as diagonal points, and the total number of fragments falling into different parts is calculated, as shown in Figure 6. From the graph, it can be seen that it is symmetrically distributed along the centerline, with the most in the middle, which is about 1.3 times the size of the edge.

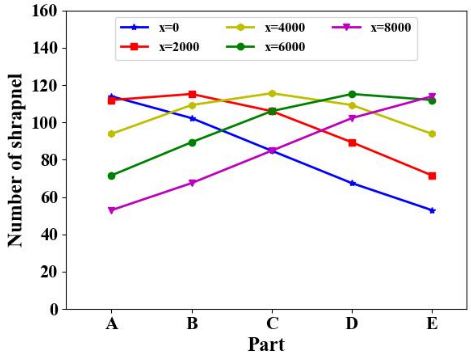

Figure 5. When y=6000, the Number of Fragments Hitting Each Part at Different x Values

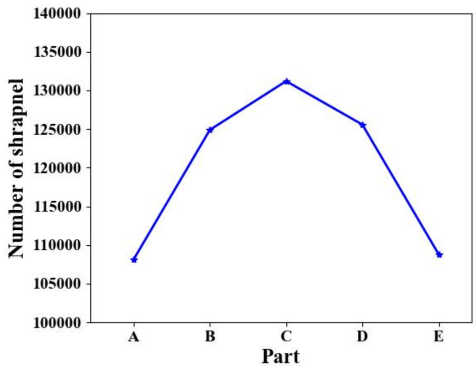

Figure 6. The Number of Fragments Hitting Each Part with 1000 Warheads

4. Recommendations for Vehicle Spare parts and Repair Tools

Taking a medium-sized transport vehicle produced by Shaanxi Automobile as an example, the components in each part that are prone to damage and affect the vehicle's ability to function after damage are shown in table 1.

Table 1. Vulnerable and Critical Components

Part	Critical components
A	Electronics
B	Tyre; Coolant hose; Oil pipe Gasholder; Preheating device
C	Battery; Main fuel tank Auxiliary fuel tank; Oil pipe
D	Tyre
E	Tyre

According to the previous calculation of the number of fragments, the number of fragments that hit part C is the highest. In part C, vulnerable components include batteries, fuel tanks, and oil pipes. The fuel tank has a large volume, a large exposed area, and a high density of debris in the area, so there is a high probability that the fuel tank will be damaged by perforation. If carrying fuel tank spare parts, it will take up a lot of carrying capacity. It is better to use welding and other sewing methods to repair the perforation of the fuel tank. Although the exposed area of the oil pipe is small and not easily hit by debris, the oil pipe appears in parts B and C, with a total exposed area of considerable size. Moreover, if the oil pipe is damaged, the vehicle will immediately lose power, seriously affecting maneuverability. Therefore, it is advisable to prepare spare oil pipes and quick connectors appropriately during travel tasks. Damaged batteries can make it difficult for the vehicle to start or stop. The large volume and weight of the battery make it unsuitable for carrying with the vehicle. Measures such as carrying an emergency power source or adding a bulletproof shell around the battery can be taken.

The damaged components in part D and E are mainly tires. The exposed area of tires is large, making them susceptible to perforation and damage from fragments. Moreover, they are distributed in multiple areas, greatly increasing the probability of damage. If the tire is damaged by a small amount of debris, stitching measures can be taken to ensure the vehicle's maneuverability; if damaged by a large amount of debris, the tire can be replaced directly. Therefore, when carrying out tasks, one should carry sewing tools and an appropriate amount of spare tire.

The vulnerable components of part B include gasholder, coolant hose, oil pipes, and fuel preheating devices. After the air storage tank is damaged, it temporarily does not affect the vehicle's movement, and the volume of the air storage tank is large, making it difficult to carry. Therefore, welding or other forms of sewing technology are also adopted. The exposed area of the coolant hose is slightly larger than that of the oil pipe, but it only exists in part B. After being damaged by fragments, it only causes coolant leakage, affecting the engine's output power and does not affect the vehicle's movement for a short period of time. Moreover, the coolant pressure inside the pipe is relatively low, and the technical requirements for maintenance are relatively low. Therefore, there is no need to carry a dedicated coolant hose during travel tasks. When the water pipe is damaged, a universal adhesive method can be used for repair. Only when the vehicle is driven at low temperatures, damage to the fuel preheating device will cause a decrease in vehicle power and will not cause the vehicle to crash, so there is no need to carry the fuel preheating device.

The vulnerable components in part A include electronic devices. When the shrapnel penetrates the car door, it will cause damage to the electronic components at the dashboard. The electronic components have a small volume and almost do not occupy the capacity of spare parts, so they can be carried with accessories appropriately.

5. Conclusions

This study established a tractor model and combined it with a damage model of fragment warhead to analyze the law of the number of fragments hitting five parts of the vehicle at different landing points. Then, by randomly generating 1000 landing points, the law of gradually decreasing fragments from the middle to both ends of the vehicle was obtained. Finally, emergency repair plans for various components in each part were proposed, providing some reference for the preparation of spare parts and repair tools for tractors during combat.

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