The Safety Analysis of Shipborne Ammunition in Fire Environment

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Abstract. The safety of Ammunition has always been the focus of national military science and technology issues. And fire is one of the major safety threats to the ship’s ammunition storage environment, In this paper, Mk-82 shipborne aviation bomb has been taken as the study object, simulated the whole process of fire by using the FDS (Fire Detection System) software. According to the simulation results of FDS, ANSYS software was used to simulate the temperature field of Mk-82 carrier-based aviation bomb under fire environment, and the safety of aviation bomb in fire environment was analyzed. The result shows that the aviation bombs under the fire environment can occur the combustion or explosion after 70s constant cook-off, and it was a huge threat to the ship security.

1. Introduction
Due to the risk of ammunition internal charge, the threat of ammunition safety from their typical instincts from the outside world comes from the essential safety response. When the ammunition in the fire and other high temperature incentives, ammunition by the high temperature environment baking, not only will accelerate the decomposition of ammunition internal charge, when the temperature is too high or the role of a long time, and even cause internal charge burning and explosion. In this paper, Mk-82 carrier-based aviation bombs as the object of study, first of all, the essential safety of aviation bombs for the analysis of a type of ship ammunition compartment model, the use of Fire Detection System software on ammunition compartment fire the whole process. Simulation of Mk-82 carrier-based aviation bombs based on FDS simulation results is carried out by ANSYS software. The temperature field analysis of aerial bombs under high temperature excitation is carried out, and the safety of aviation bombs in fire environment is analyzed.

2. The essential safety of aviation bomb
2.1. The structure of the aviation bomb
In this paper, Mk-82 carrier-based aviation bombs for the study of security analysis and modeling and simulation. Mk-82 carrier-based aviation bombs contain 218.7 kg of TNT explosives. The structure of the diagram shown in Figure 1.
2.2. The safety of the aviation bomb charge

The basic reaction forms of explosives are pyrolysis, combustion, explosion and detonation. In a certain stimulating environment, the four reaction forms can be converted to each other. As the ship environment is poor, in the event of strong stimulation, easy to reach the critical point of explosives, so that the chemical reaction and then may explode and so on [1][2]. Set the explosives to occur in the unit time to release the heat of $Q_1$, mainly depends on the reaction rate $W$ and the explosive unit after the quality of the heat released after the $Q$:

$$Q_1 = W \cdot q$$

(1)

$$W = z e^{\frac{E}{RT}} \cdot m$$

(2)

Where $z$ is the frequency factor, $E$ is the activation energy of the explosive, $m$ is the mass of the explosive, and $R$ is the gas constant.

$$Q_1 = z e^{\frac{E}{RT}} \cdot m \cdot q$$

(3)

The amount of heat dissipated by heat conduction per unit time is set to $Q_2$,

$$z e^{\frac{E}{RT}} \cdot m \cdot q = K (T - T_0)$$

(4)

The conditions for reaching the explosion are $Q_1 = Q_2$, and $Q'=Q_2'$, with:

$$(T - T_0) \frac{E}{RT_0^2} \approx 1$$

(5)

$$e^{\frac{E}{RT}} \cdot z \cdot m \cdot q \cdot E \cdot RT^2 = K$$

(6)

take (5) & (6),

$$(T - T_0) \frac{E}{RT_0^2} \approx 1$$

(7)

The explosion temperature $T$ of the explosive is obtained from the ambient temperature $T_0$ of the explosive. TNT at the heating temperature of 130 °C, heating time 100h, no decomposition. Heating temperature reached 160 °C, began to break down, resulting in gas decomposition products. Heating temperature of 240 °C, heating time 0.5h after the combustion [3][4]. The burst temperature is shown in Table 1,
Table 1. The explosion temperature of TNT.

| Temperature/°C | Time/s |
|---------------|--------|
| 570           | 0.01   |
| 520           | 1.0    |
| 475           | 5.0    |
| 465           | 10.0   |

In the evaluation of the thermal sensitivity of explosives, the general use of ignition point to determine the sensitivity of explosives. Table 2 for some of the ignition temperature parameters of the ignition.

Table 2. The 5s Ignition point of some explosive

| Explosive | TNT | Tetryl | Hexogen | Nitroglycerin |
|-----------|-----|--------|---------|--------------|
| Ignition point/°C | 475 | 257    | 260     | 222          |

3. The fire simulation of Ammunition compartment

3.1. Build the ammunition compartment model

According to the structure and size of the compartment and the ammunition storage mode while ignoring the small impact on the fire in the structure[5] (such as switches, lights, floor configuration of the matrix type retaining holes, etc.) modeling, as shown below:

![Simulation model of ammunition compartment](image)

Figure 2. Simulation model of ammunition compartment

Blue structure for the bulkhead, the material is steel. Gray structure for the ammunition tray, material for the steel. Black structure for the cable, the material for the PVC. Green, purple structure for the illegal stacking items, respectively, wood, cotton and other solid combustibles and fuel (THCP) is the temperature measuring device. The blue mark part (SPRK) above the compartment is the spraying equipment. The red mark part is the fire source.

3.2. Set the heat release rate of compartment fire

As the fire from the beginning of the ignition process on the impact of the fire is very small, so in practical applications, generally only study the fire after the effective combustion of the fire state, regardless of the effective fire before the stage of combustion, take $t_0=0$. Simplified as formula (8):

$$Q = \alpha t^2$$  (8)
As mentioned above, according to the fire development characteristic curve, taking into account the assumption of combustible species, combined with Table 3, it is assumed that the fire scene is between fast fire and ultra fast fire, so take the fire growth coefficient of 0.11 K\(_w/S^2\) [6].

| Fire category     | Typical combustibles            | Fire growth factor (K\(_w/S^2\)) | The heat release rate reaches 1 MW |
|-------------------|---------------------------------|-----------------------------------|-----------------------------------|
| Slow fire         | Hardwood                        | 0.002931                          | 584                               |
| Medium speed fire | Cotton, polyester material      | 0.01127                           | 292                               |
| Fast fire         | Cartons, stacks, foam           | 0.04689                           | 146                               |
| Ultra-fast fire   | Light cotton curtains and other home textiles | 0.1878                          | 73                                |

The heat release rate can be set to 1100 K\(_w/m^2\) by the formula (8), according to Table 3, the fire development time is 100s.

3.3. Simulation results and analysis

In the compartment fire simulation model, a thermocouple was set up to record the temperature changes at the two points during the fire process, respectively, at the nearest and farthest ammunition shelves of the fire source. Two temperature slices record the surface data, the time is set to 300s. The simulation results are as follows:

Figure 3. Near fire source temperature recording point

Figure 4. Far fire source temperature recording point

Figure 5. Shows the 30s ammunition plane temperature profile

Figure 6. Shows the 150s ammunition plane temperature profile

Figure 3 and Figure 4 can also be seen in the vicinity of the fire source and the point away from the ignition point of the temperature difference is not, so the hazards of the compartment fire is global. The compartment temperature can reach 770 °C, and will cause harm to the entire
In actual fires, combustible species are often more complex and large, so the resulting fire will be more threatening.

4. Simulation of Aviation Bomb Temperature Field

4.1. Build model
The Mk-82 carrier-based aviation bomb structure is simplified and can be approximated as a long cylinder. Therefore, the axisymmetric unit is chosen to carry out two-dimensional heat conduction analysis. The material is steel, the internal main charge for the TNT, transmission tube material for the polyethylene plastic, pass the drug for the passivation of Penthrite[7][8]. The material properties of the parameters shown in Table 4.

| Material       | Density (kg/m³) | Thermal Conductivity (w/m·k) | Specific heat (J/kg·k) |
|----------------|-----------------|------------------------------|------------------------|
| TNT            | 1570            | 0.24                         | 1760                   |
| Penthrite      | 1684            | 0.1165                       | 1088                   |
| Adapter booster| 1200            | 0.19                         | 2303                   |
| Steel          | 7850            | 70                           | 448                    |

4.2. Initial conditions and boundary conditions
Assuming ammunition chamber and the initial temperature of the bomb are 25 °C, ammunition compartment fire or ammunition explosion and other accidents, resulting in high-temperature energy bombing of the bomb. The temperature of the ammunition capsule is set to 1200 °C. It can be seen from Table 5 that the thermal conductivity of the missile is 70 w/m·k, and the thermal conductivity of the TNT is 0.24 w/m·k. The thermal conductivity is 0.19 w/m·k, and the ignition time is 5 min.

4.3. Analysis of Temperature Field
In the simulation model, the temperature analysis of the aviation plane is analyzed by transient analysis. First, the initial temperature of the missile, the main charge and the main point of the burst tube is set, and the time and step length of the model are analyzed for 0.01s, and the initial temperature of the missile is obtained. And then set the temperature field in the compartment to set the temperature, set the temperature of 1200 °C, time 300s, step length 0.01s, detection time of 5s, after calculation, the aviation plane temperature field cloud, thermal density cloud, The temperature of the shell, the surface of the charge, the charge medium, the charge center, the surface of the breaker and the surface of the booster surface within 300s.
Figure 7. Temperature field image of Ammunition in fast cook-off

Figure 8. Temperature changing of the booster drug

Figure 9. Temperature changing of the booster

Figure 10. Temperature changing of one node near the shell

Figure 11. Temperature changing of Center node of main equipment drug
4.4. Simulation results analysis

Through the calculation and analysis of the temperature field of the aeronautical bombs under the fast baking and firing, the temperature change of any node of the aviation bomb can be obtained. Assuming that in the fire environment excitation process, the aircraft charge internal charge without reaction under the premise of Figure 12 shows that in the rapid baking of 300s, the shell temperature of the rapid rise, reaching 818.5°C. The internal temperature changes of the charge are also tracked to obtain the trend of temperature change shown in Figure 12 and Figure 13. After analysis, the temperature rise of the internal charge near the missile body is also obvious due to the strong external temperature stimulus 60s, the charge temperature began to rise, after 300s to 36.018°C, and the internal transmission tube, the temperature change is not as slow as the slow burning. After 300 seconds, the maximum temperature of the burst tube is 25.007°C, almost have no changes.

5. Conclusion

According to the safety analysis of the main charge of this type of aviation bomb and the simulation of the fire process in Section 2.2 and Section 3.3 of this paper, the burst temperature of TNT burst period is 10s and the burst temperature is 465°C, and the bursting period is 10s off the burst point temperature of 211 °C. It can be seen from the trend of the bomb temperature in Figure 12 with the trend of burning time, when the rapid baking excitation time of 1200°C for 65s after the bomb temperature reached 470 °C, TNT has exceeded the 10s burst temperature, and the body temperature Continue to rise. So in the rapid baking inspiration, the missile in the continuous incentive time for 70s TNT explosives in the high temperature stimulation will occur under the combustion or explosion reaction. So the fire environment on the security of aviation bombs threatened, when the fire occurs, it must be extinguished within 60s to save the ship.

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