Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (22): 5478-5482, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.5478.5482

Thermal Characteristic Analysis of Balloon Decoys in Flight Midcourse of Ballistic Missile

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Abstract: Balloon decoys technology is a successful penetration method of ballistic missile in flight midcourse. The radar can't recognize the warhead if the nuclear warhead is hidden in a metal balloon. But the temperatures of balloon decoy and balloon with warhead are different because the warhead can transmit heat to the balloon, then the infrared detectors in missile recovery system will distinguish the nuclear warhead according to the temperature difference. Aiming at this problem, we studied thermal characteristic of balloon decoys which are released is analyzed theoretically under two different conditions, namely, day attack and night attack in this study. Thermal balance temperature and the necessary time to reach balance temperature of balloon decoys are calculated. Temperature trend of balloon with warhead in midcourse is analyzed quantitatively. The measures to eliminate all kinds of heat effects between nuclear warhead and balloon are put forward by use of proper surface coat in day attack. At night attack, the infrared detector can't distinguish balloon with warhead from balloon decoys after we adopt corresponding active countermeasures and passive countermeasures.

Key words: Balloon decoys, penetration, thermal characteristic

INTRODUCTION

Decoys are a kind of effective penetration means of ballistic missile and they are studied deeply and applied abroad in many countries. Anti-simulation decoy technology is referred to disguise the nuclear warhead and eliminate the difference in shape, electromagnetism reflected characters, temperature and weight from the decoys, then penetrate the missile recovery system (Liu, 2003).

The most successful anti-simulation decoy technology is to put the nuclear warhead in the metal balloon baits. In the flight midcourse, the empty balloons and the balloons with warhead will be released at the same time. Because the radar detective beams can't penetrate the flimsy metal coat of balloons, the inside objects can't be recognized. Whereas the nuclear warhead can release the heat and transmit it to the outer balloons and this heat conduction will induce the temperature difference between the balloons with nuclear warhead and empty balloons. The real warhead will be recognized by the infrared detectors of ballistic missile recovery systems according to the thermal difference between them. So, it is very important and practical to study the thermal characters of balloon decoys in fight midcourse of ballistic missiles.

The thermal characteristics of released balloon decoys are analyzed theoretically in day attack and night attack in this study. The thermal balance temperature of balloon decoys and the necessary time to achieve thermal balance are calculated. The trend of temperature change of balloons with warhead is analyzed quantitatively. The measures to eliminate the temperature difference between balloon decoys and balloons with warhead are put forward and they can reduce the real warhead reorganization probability by infrared detectors.

Thermal characters of balloon decoys

Thermal balance temperature of balloon decoys: Because the midcourse of ballistic trajectory almost approaches the vacuum space, there are no heat exchange and convection to transmit heat except heat radiation (Chen, 2001). So, we can deduce the theoretic formula of balloon decoys temperature change rule and achieve the analytic results.

Before the balloon decoys don't reach thermal balance, the power of absorbed energy and radiant energy are equal to the increasing rate of inner energy (Yao *et al*., 2005; Chen, 2007), which is shown as Eq. 1:

$$\dot{Q}_{in}+\dot{q}_{in}-\dot{Q}_{out}=\frac{dq}{dt}=MC(\frac{dT}{dt}) \tag{1}$$

where, $\dot{Q}_{in}$ is the energy that balloons decoy absorbs from the celestial bodies, $\dot{q}_{in}$ is the heat from the inner heat source of balloon, $\dot{Q}_{out}$ is the radiant power to the space, M is the quality of balloon decoy, C is the specific

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heat of surface material of balloon decoy, $\frac{dT}{dt}$ is the surface temperature varying rate of balloon decoy.

When the balloon decoy reaches thermal balance temperature T_e, the temperature will be changeless, so $\frac{dT}{dt} = 0$; There is no heat sources in the empty balloons, so $q_{in} = 0$. The Eq. 1 can be rewritten as:

$$\dot{Q}_{in} = \dot{Q}_{out} \tag{2}$$

Balloon decoys in day attack: To the balloon decoy in daytime, $\dot{Q}_{in}$ includes three parts, namely, the energy absorbed from sun, reflected sun radiation from earth and infrared radiation from earth. That is:

$$\dot{Q}_{in} = [\alpha E_1 + \frac{(\alpha E_2 + \varepsilon E_3)}{(1 - H/R)^2}]\overline{A_p(\theta, \varphi)} \tag{3}$$

where, E_1 is the sun energy flux, which is about 1360 Wm^{-2}; E_2 is the reflected sun energy flux from earth surface (h = 0), which is called as flash back flux and is $0.3\,E_1$; E_3 is the infrared flux of earth, which is about 40 W m^{-2}; α is the sun absorptivity of surface material of balloon decoy; ε is the infrared emissivity of surface material of balloon decoy; H is height of balloon decoy from earth, R is the radius of earth; $\overline{A_p(\theta, \varphi)}$ is the average value of projection area when the longitude and latitude are (θ, φ) of the balloon decoy to the celestial body.

The height of balloon decoy is very low and can be omitted compared to the earth radius, namely, $H/R \to 0$, so we can rewritten Eq. 3 as:

$$\dot{Q}_{in} = [\alpha E_1 + \alpha E_2 + \varepsilon E_3]\overline{A_p(\theta, \varphi)} \tag{4}$$

There are no conduction and convection in $\dot{Q}_{out}$ because there is no air in the outer space. We suppose that the balloon decoy rotates ceaselessly and the surface is radiated by sun equally, so the surface temperature is the same. $\dot{Q}_{out}$ can be shown as Eq. 5 after reaching balance temperature under these conditions:

$$\dot{Q}_{out} = \varepsilon A\sigma(T_e^4 - T_s^4) \tag{5}$$

where, A is the surface area of infrared radiation; σ is the Steven-Balzeman count, which is 5.67×10^{-8}W m^{-2} K^4; T_e is the average temperature of balloon decoy, T_s is the background temperature of outer space, which is 3.9 K.

From Eq. 2, 4 and 5, we can get:

$$T_e = \left\{\left[\frac{\alpha}{\varepsilon}\left(\frac{E_1 + E_2}{\sigma}\right) + \frac{E_3}{\sigma}\right]\frac{\overline{A_p(\theta, \varphi)}}{A} + T_s^4\right\}^{\frac{1}{4}} \tag{6}$$

Because the balloon decoy can be seen as a sphere:

$$\frac{\overline{A_p(\theta, \varphi)}}{A} = \frac{\pi r^2}{4\pi r^2} = \frac{1}{4}$$

in Eq. 6. So,the balance temperature T_e only direct ration to α/ε in the empty balloon decoy, namely, it is direct ratio to the ratio between the absorptivity and infrared radiance of surface material of balloon decoy.

Table 1 shows the absorptivity and infrared emissivity of many kinds of materials (Sessler *et al*., 2000; Xie *et al*., 2001; Mu *et al*., 2007) and we calculate the balance temperature of balloon decoy in day time according to Eq. 6:

Balloon decoy as night attack: The balloon decoy at night lies in the shadow of the earth and $\dot{Q}_{in}$ only includes the absorbed energy from earth infrared radiation. The balance temperature T_e is:

$$T_e = \left(\frac{E_3}{4\sigma} + T_s^4\right)^{\frac{1}{4}} \tag{7}$$

We can calculate T_e = 180.4 K. So, when the balloon decoy lies in the shadow of the earth, the balance temperature is about 180K and irrelevant with the material and surface coat of the balloon decoy.

Table 1: Visible light absorptivity, infrared emissivity and balance temperature of various materials

Surface coat	α	ε	α/ε	Balance temperature of balloon decoy in the day (K)
White TiO_2 dope	0.190	0.940	0.20	226.5
White annulus oxygen dope	0.248	0.924	0.27	236.9
white lacker	0.252	0.853	0.30	240.8
Mylar	0.170	0.500	0.34	246.8
Aluminum silicon dope	0.250	0.280	0.89	299.2
Grey TiO_2 dope	0.870	0.870	1.00	306.7
Dark lacquer	0.975	0.874	1.12	314.3
Aluminum-based dope	0.540	0.450	1.20	319.4
Aquadag dope	0.782	0.490	1.60	340.9
Aluminum foil	0.192	0.036	5.33	454.4
Polishing golden plating layer	0.301	0.028	10.8	539.7

Necessary time to reach balance temperature : Before the balloon decoy reaches the thermal balance, we can show the time varying rules of balloon decoy's temperature in the day and at night as Eq. 8 and 9 according to Eq. 1-5:

$$\left(\frac{MC}{\varepsilon A}\right)\frac{dT}{dt}=\left[\frac{\alpha}{\varepsilon}\frac{(E_1+E_2)}{4}+\frac{E_3}{4}+\sigma T_s^4\right]-\sigma T^4$$

$$\left(\frac{MC}{\varepsilon A}\right)\frac{dT}{dt}=\left(\frac{E_3}{4}+\sigma T_s^4\right)-\sigma T^4$$

Where:

$$\frac{MC}{\varepsilon A}$$

is the heat capacity per unit effective radiate area and can be expressed as:

$$\frac{MC}{\varepsilon A}=\rho\delta C$$

where, ρ is density, δ is the thickness, $\rho\delta$ is the surface density.

We take the balloon model adopted in the American space experiment as an example introduced in reference (Sessler *et al*., 2000) to explain the rules of balloon decoy reaching thermal temperature. In the space examination, the USA army adopts the ball with double layers whose diameter is 3 m. There are two projects about the balloon decoy, one is the balloon decoy with thin material whose outer layer is 0.00025cm thick aluminum foil and inner layer is 0.00064cm mylar; The other is balloon decoy with thick material whose outer layer is 0.0025 cm thick aluminum foil and inner layer is 0.0025 cm mylar. The parameters of aluminum foil are ρ = 2.7 g cm^{-3}, ρ = 0.904 J g^{-1}●K; The parameters of mylaer are ρ = 1.39 g cm^{-3}, ρ = 1.15 J g^{-1}●K.

Suppose the initial surface temperature of balloon decoy is 300 K. We draw the temperature change curve of balloon decoy in the daytime according to Eq. 8~10 by MATLAB software (Liu and Peng, 2003) as Fig. 1.

The balloon decoy with thin material is shown in Fig. 1a and we can see that it needs about 1~2 min to reach thermal balance temperature when the initial temperature is 300 K. At the same condition, the balloon decoy with thick material shown in Fig. 1b needs ten minutes or so. From Fig. 1, we can know that if the difference between the initial temperature and the thermal balance temperature of releasing balloon decoy is very great, the temperature of balloon decoy can reach the balance temperature quickly because of its low heat capacity. The necessary time to reach balance temperature depends on two facets, namely, the temperature difference between the initial temperature and the balance temperature and the heat capacity of balloon decoy.

At night, the balloon decoy with thin material takes two minutes to reach balance temperature 180 K or so and that with thick material takes more than ten minutes to reach thermal balance. The necessary time is irrelevant with the surface coat.

Thermal characters of balloon with warhead: Compared to the empty balloon decoy, the warhead has larger quantity and greater heat capacity and will take several hours to reach thermal balance. The warhead in the balloon will influence the heat performance of the balloon after releasing the balloon and warhead to the outer space. The heat will be transmitted from the warhead to the balloon (or from the balloon to the warhead) by four ways: Heat radiance, heat conduction through the securing pole fastening the warhead, heat conduction through air in the balloon and the gas convection induced by movement. The heat radiance and the gas convection are main factors to influence the balloon temperature change.

In the day, the balance temperature of balloon depends on the surface coat and the temperature will rise or descend quickly. The temperature of the warhead in the balloon changes slowly. The warhead will transmit the heat to balloon through above four ways and make the temperature of balloon near to the releasing initial temperature.

It is very different to attack at night compared to in the day. The only outer heat source is the infrared radiance from earth at night. The balance temperature of balloon decoy will stay 180K. The influence to the warhead in the balloon is very great in such low balance temperature and it is about 200K generally (Guo and Zhao, 2004).

Penetration measures analysis: We can see from above analysis that the thermal characters of balloon decoy and the balloon with warhead is different after releasing. If we don't adopt appropriate measures, the infrared detectors will distinguish the objects easily. We analyze the penetration measures in the day and at night as follows:

- **Day attack:** The difference of thermal characters between balloon decoy and balloon with warhead in day attack is obvious. The temperature of balloon decoy will rise or descend to the balance temperature quickly and the balance temperature depends on the surface coat of decoy. The temperature of balloon with warhead will rise or descend to the releasing initial temperature

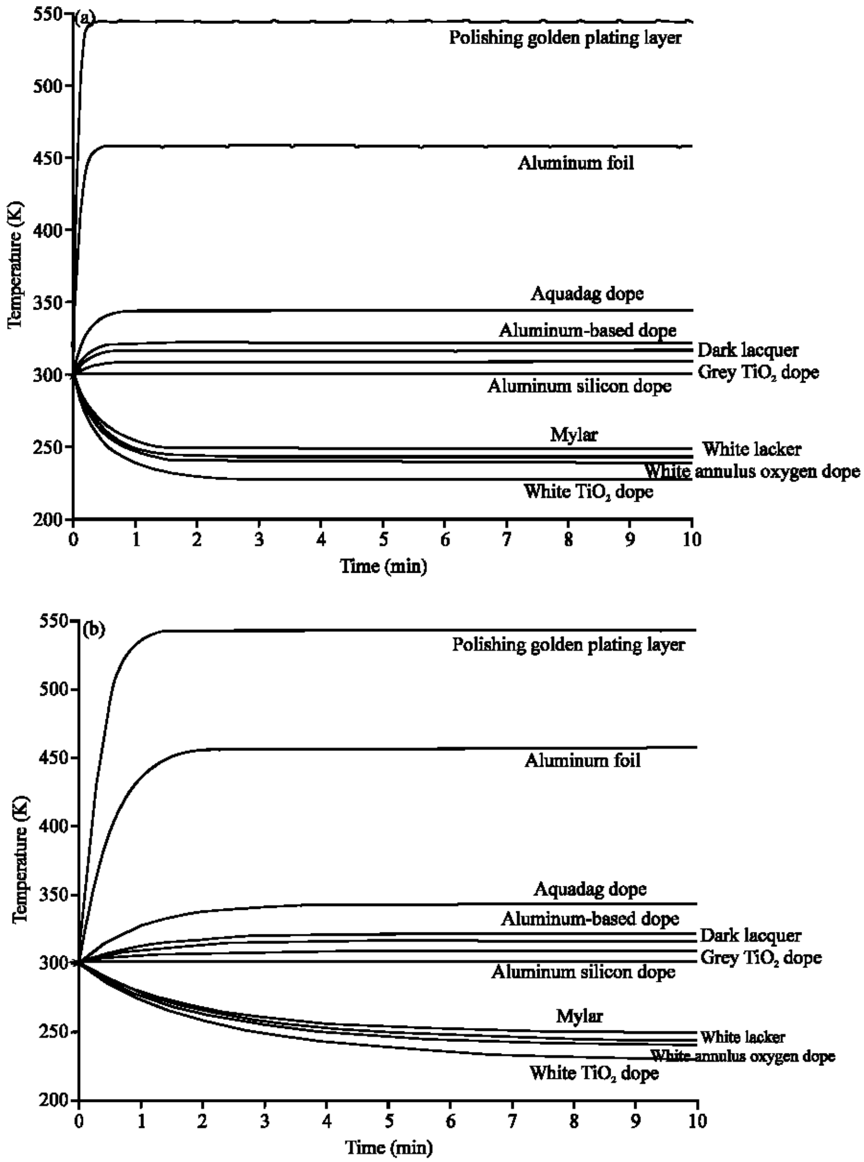

Fig. 1(a-b): Curve of balloon decoys temperature change with time in daytime

If the difference between the balance temperature and the releasing initial temperature of balloon decoy is great, the infrared detectors will recognize the warhead easily. We can choose appropriate surface coat of balloon decoy and make the balance temperature near to the initial temperature of nuclear warhead in day attack. This measure can eliminate all kinds of heat effects induced by nuclear warhead. For example, if the initial temperature of warhead is close to room temperature (300 K), we can brush aluminum silicon dope on the balloon surface and make the balloon temperature change about 300 K. We can prevent all the infrared detectors in the missile recovery system from recognizing the balloon with nuclear warhead and balloon decoy.

Night attack: The balance temperature of balloon with warhead is 20 K higher than that of balloon decoy at night. We can adopt active countermeasure and passive countermeasure to prevent infrared detectors from detecting the warhead,

Active countermeasure: The temperature of balloon decoy can be increased to the temperature of balloon with warhead by using a small heater supplied power by battery. Passive countermeasures: We can choose the super insulated material or low radiate material, such as luculent aluminum foil or polishing silver plating layer, to overcast the nuclear warhead to reduce the heat conduction from warhead to balloon; we also can use balloons with different shapes. These balloons will possess different balance temperature and the changing value is only few degrees. The warhead will be hidden one of them and the infrared detectors in the missile recovery system can't distinguish the balloon with warhead.

CONCLUSION

This study studied the thermal characters of balloon decoy in midcourse of flight. We analyze the balance temperature of balloon decoy and the necessary time to reach thermal balance and deduce the calculating formula in day attack and night attack firstly. Then we calculate the balance temperature value by MATLAB according to the concrete data and draw the temperature change curve of balloon decoy after releasing. Secondly, we analyze the thermal character of balloon with warhead quantitatively and point out the reason to induce temperature difference between it and balloon decoy. Finally, the penetration measures are put forward in day attack and night attack and they are very practical.

We only analyze the thermal character of balloon decoy in sphericity. The next problem to study is the thermal character of balloon decoy in other shapes.

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