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# Theoretical analysis of the surface temperature regulation of an infrared false target subjected to periodical ambient conditions

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## Abstract

Infrared false target is an important mean to induce the infrared-guided weapons, and the key issue is how to keep the surface temperature of the infrared false target to be the same as that of the object to be protected. One-dimensional heat transfer models of a metal plate and imitative material were established to explore the influences of the thermophysical properties of imitative material on the surface temperature difference (STD) between the metal plate and imitative material which were subjected to periodical ambient conditions. It is elucidated that the STD is determined by the imitative material's dimensionless thickness ($d_{im}^*$) and the thermal inertia ($P_{im}$). When $d_{im}^*$ is above 1.0, the STD is invariable as long as $P_{im}$ is a constant. And if the dimensionless thickness of metal plate ($d_m^*$) is also larger than 1.0, the STD approaches to zero as long as $P_{im}$ is the same as the thermal inertia of metal plate ($P_m$). When $d_{im}^*$ is between 0.08 and 1, the STD varies irregularly with $P_{im}$ and $d_{im}^*$. However, if $d_m^*$ is also in the range of 0.08–1, the STD approaches to zero on condition that $P_{im} = P_m$ and $d_{im}^* = d_m^*$. If $d_{im}^*$ is below 0.08, the STD is unchanged when $P_{im} d_{im}^*$ is a constant. And if $d_m^*$ is also less than 0.08, the STD approaches to zero as long as $P_{im} d_{im}^* = P_m d_m^*$. Furthermore, an application-oriented discussion indicates that the imitative material can be both light and thin via the application of the phase change material with a preset STD because of its high specific heat capacity during the phase transition process.

*Keywords:* Infrared false target; Surface temperature; Periodical ambient conditions; Thermal inertia; Dimensionless thickness

## 1. Introduction

The infrared detection technology has been widely explored in the military domain, such as infrared precise guidance, search and tracking. With its continuous development, the spatial resolution of the infrared detectors is getting higher [1,2], and the infrared image generation models are getting more accurate [3,4]. Especially, along with the use of the human visual characteristics for detection, the infrared detection technology has achieved a remarkable development because the human vision has a selective attention property which is helpful to search the target from a complex background quickly and precisely [5,6]. The infrared target detection based on visual attention can be sorted into two types. One is that the saliency map is composed of individual feature maps, some of which are extracted from input image [7], and the other is that the saliency map is obtained via the statistical information of natural scene [8]. In other words, the infrared detection tends to be combined with the human vision image in the future, which induces the urgent requirement of the infrared defence of the object to be protected. As one of the effective defence technologies, the infrared false target has been extensively studied for decades, and the regulation of its surface temperature, the most important factor in the infrared defence, is increasingly stringent. From the aforementioned relevant introduction about infrared detection, it can be expected that the only way to adapt to the future infrared defence challenges is to develop a false target having the same surface temperature and the same surface radiative properties (solar absorptance and infrared emissivity) as the object to be protected.

It is of vital importance to understand how the thermophysical properties of false target influence the surface temperature difference (STD) between it and the object to be protected. Therefore, the relationship between the STD and the thermophysical property difference between the object to be protected and the false target was discussed subjected to the same periodical ambient conditions, and the rules on how to make the false target have the same surface temperature as the

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object to be protected were proposed. Besides, from the perspective of the practical application, the advantages and disadvantages of the phase change material and the non-phase change material were discussed, and the specified properties of the imitative material to make the STD approach to zero were evaluated.

## 2. Model

The object to be protected discussed here is reasonably assumed as a rectangular cabin, and the focus of exploration is the top cover of cabin which is the most important surface for the infrared defence. Because the top of the object to be protected is usually a metal plate, the goal of the work is to imitate a horizontal metal plate subjected to periodical ambient conditions. The one-dimensional heat transfer models of metal plate and imitative material, i.e., the featured surfaces of the object to be protected and the false target, were established to explore the influence of the difference of their thermophysical properties on the STD under the same periodical ambient conditions. Their top surfaces are exposed to the ambient environment, and the adiabatic boundary conditions are applied to their bottom surfaces from a practical consideration, as shown in Fig. 1. The possible application of metal plate and imitative material would be the surface cover of special equipment usually operating at high or low temperature (relative to the ambient temperature), which would form a strong thermal boundary condition for the bottoms of them. However, there is usually a thick thermal insulation layer around the equipment to make its operation stable. Considering the high-performance of thermal insulation layer, an adiabatic boundary condition over the bottoms of metal plate and imitative material can be a good approximation.

A one-dimensional heat transfer assumption is reasonable for both the metal plate and the imitative material, and their governing equations take the same form

$$\rho c_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} \tag{1}$$

where $\rho$, $c_p$ and $k$ are density, specific heat capacity and thermal conductivity, respectively. As shown in Fig. 1, the boundary conditions of metal plate and imitative material are identical. Their top boundary conditions can be similarly expressed as

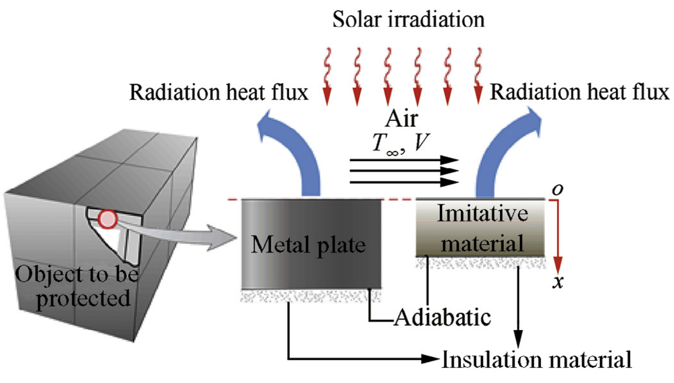

Fig. 1. Schematic diagram of metal plate and imitative material.

$$-k\left.\frac{\partial T}{\partial x}\right|_{x=0} = q'' = G_{abs} - Q_{rad} - Q_{conv} \tag{2}$$

and the bottom boundary conditions are both adiabatic. In Eq. (2), $q'' = G_{abs} - Q_{rad} - Q_{conv}$ is the net heat flux into the top boundary, $G_{abs}$ is the solar irradiation absorbed by the top surface, $Q_{rad}$ is the radiation heat flux between top surface and sky, and $Q_{conv}$ is the convection heat flux between top surface and air. $G_{abs}$ is equal to $\alpha_s G_{sol}$, where $\alpha_s$ represents the solar absorptance and $G_{sol}$ represents the solar irradiation. $Q_{rad}$ is equal to $\varepsilon\sigma\left(T_s^4 - T_{sky}^4\right)$, where $\varepsilon$, $\sigma$, $T_s$ and $T_{sky}$ represent infrared emissivity, Stefan–Boltzmann constant, top surface temperature and effective sky temperature. $Q_{conv}$ is equal to $h\left(T_s - T_\infty\right)$, where $h$ represents the convection coefficient estimated by $h = 5.7 + 6.0V$ [9] ($V$ is the wind speed), and $T_\infty$ represents the temperature of air flow. The correlation used here for computing convection coefficient is selected according to the recommendation of a survey of wind convection coefficient correlations in Ref. 9 which is commonly used to calculate the convection coefficient over a flat plate by taking both the natural and force convections into account. And its reliability has been commonly accepted.

To develop the false target which has the same infrared characteristics as the metal plate, the radiative properties of metal plate and imitative material, i.e., $\alpha_s$ and $\varepsilon$, are set to be the same, which can be realized by the same coating. The contact resistance between the coating and the metal plate or the imitative material can both be neglected, and the coating can be very thin so that its influence on the surface temperature can also be neglected. The material properties are assumed to be constant. This assumption was adopted because the metal plate and the imitative material are both not specified, and there are no general variation laws of their properties with temperature so that the variation of properties with temperature is difficult to be considered. Hence, we did not consider the temperature dependencies of the related thermal properties of metal plate and imitative material. However, the results below can be taken as a reasonable approximation.

## 3. Results and discussion

### 3.1. Theoretical analysis

Here we define a dimensionless independent variable

$$\eta = \frac{x}{\delta_{p,im}} \quad (x \geq 0) \tag{3}$$

where $\delta_{p,im}$ represents the heat penetration depth and is equal to $4\sqrt{k_{im}/\left(\omega\rho_{im}c_{p,im}\right)}$ [10], where $\omega$ stands for the variation frequency of ambient condition which can be calculated as $\omega = 2\pi/86400\ \mathrm{s}^{-1}$. The governing equation and the boundary conditions of the imitative material can then be rearranged as

$$\begin{cases} \dfrac{\partial T}{\partial t} = \dfrac{\omega}{16} \cdot \dfrac{\partial^2 T}{\partial \eta^2} \\ -\left.\dfrac{\partial T}{\partial \eta}\right|_{\eta=0} = \dfrac{1}{4}\sqrt{\dfrac{\omega}{k_{im}\rho_{im}c_{p,im}}} \cdot q''; \quad \left.\dfrac{\partial T}{\partial \eta}\right|_{\eta=d_{im}^*} = 0 \end{cases} \tag{4}$$