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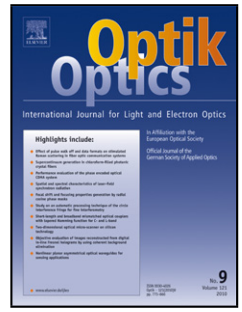

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Aerothermal radiation transfer calculation method from the dome to the detector based on reverse ray tracing

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ABSTRACT

The effect of aerothermal radiation of the optic dome on the signal-to-noise ratio of infrared detection system is becoming a crucial issue when the temperature of optic dome is increases in the high speed incoming flow. The method to calculate the radiated power transfer from the whole dome to the unit of the detector through the optic system according to the inverse ray tracing was proposed. The gradient temperature distribution of the dome surface and the attenuation coefficient of the dome material with the wavelength and the temperature were taken into considered in dome's thermal radiation calculation. According to the mothed, the simulation software was developed and used to analyze the effect about the radiated power transfer from dome of the example optic system to the detector. Simulation results show that the dome with high temperature generates more noise radiated power on the focus plane, to choose reasonable wavelength band and thickness of the dome is useful to increase the signal-to-noise ratio.

Keyword:

Aerothermal

Radiative transfer

Dome

Inverse ray tracing

1. Introduction

When infrared guided missile exposure to a supersonic flight environment, intense interactions take place between the dome of the missile and coming flow, leading to shock wave, expansion wave, turbulent boundary layer and rise in temperature of the dome. All the phenomena are called aero-optical effects [1], which will reduce signal-to-noise ratio of detection system.

There are two mechanisms to reduce signal-to-noise ratio of missile detection system under aero-optical effects. One is the non-uniform refractive index distribution of the flow field near the dome caused by the high speed coming flow that lead to imaging defects such as blur, shift, jitter[2-4]. The other one is heat radiation from the dome in high temperature that increases the noise on the focus plane array of the detector [5].

In recent years increasing interests have been created in aero optical transmission due to its severe influence on the imaging quality. C.M. Wyckham and Smits [6] used a two-dimensional Shack–Hartmann wave-front sensor to study aero-optic distortion in turbulent boundary layers at transonic and hypersonic speeds, with and without gas injection. C. Hao, et al. [7] used ray tracing program to simulate the optical transmission through the aerodynamic flow field, and found that the imaging quality of the airborne optical system was affected by the shape of the optical window and the angle of attack of the aircraft. Yang B, et al. [8] researched transmission characteristics and simulation method of starlight transmission in hypersonic conditions with the pneumatic and inhomogeneous medium for starlight navigation. Li Liu, et al. [9] builds a multi-scale analysis model of aerodynamic thermal radiation degraded images, and the model is effective in the aerothermal radiation degraded image correction, and improves the quality of the aero thermal radiation degraded image. Shouqian Chen, et al. [10] investigated the influence exerted by the aerodynamic heating of the faceted dome on imaging quality degradation of an airborne optical system. Wang Zhang, et al. [11] calculated the aerodynamic flow field surrounding the conformal dome, analyzed the thermal response of the aerodynamically heated conformal dome, rebuild the non-uniform refractive index field of the conformal dome, evaluated the imaging quality of the conformal optical system. In addition, a large effort has been devoted to tackle aero-thermal radiation [12-15]. Although many reports have been published on influenced by aerodynamically heated domes and windows, too little attention has been given to the radiation transfer from the dome to the detector through the optic system.

Generally speaking, the optical dome use material with characteristic by high transmittance in infrared band that means the material has low emissivity. The thermal radiation energy emitted by optical dome propagates to the focal plane array detectors is very weak and can be ignored. But it can't be ignored when the temperature of the dome is higher that means the thermal radiation energy emitted by the dome is higher too. The influences to target detect come from the thermal radiation of dome should be considered in this circumstances.

The objectives of this study were to find the method to calculate the radiation received by the unit of the detector from the whole dome through the optic system, and to develop the simulation software to analyze the influence of the dome's aerothermal radiation according the method. The gradient temperature distribution of the dome along the surface and the thickness, and the ray propagation principle should be considered in radiation calculation.

2. Radiation transfer calculation method based on the inverse ray tracing

The infrared thermal radiation emitted by optical dome propagates to the detector of the focal plane array through the catadioptric optical system as in fig.1. Each unit of the detector will gathers the radiated power from the whole part of dome where the ray can propagates to the unit of the detector through the optical system.

The dome surface is discretized into many area elements in which the temperature is same to facilitate the calculation the radiation power received by a unit of detector.

The radiation power received by a detector unit and came from the whole dome surface can be calculated as follow:

$$P = \sum_{dA1} L_{dA1} \cdot dA_1 \cdot \cos(\theta_1) \frac{dA_2 \cdot \cos(\theta_2)}{D^2} \quad (1)$$

Where dA_1 is the differential area element of dome, dA_2 is the area of detection unit, L_{dA1} is the radiance of the differential area dA_1, θ_1 is the angle between ray and the normal of dome surface, θ_2 is the angle between the ray and the normal of detection unit, D_{12} is the distance between the differential area element of dome and the unit of the detector.

It is very difficult to hunt for the ray from each differential area element of dome to the same detection unit. That means it is impossible to definite several parameters including angle θ_1, angle θ_2 and distance D which are associated with the ray. A novel radiation calculation method based on inverse ray traces was present as follow.

A particularly useful simplification of the radiation transfer from dome to detector was considered. Consider a simple case, there are two Lambertian surfaces that one surface denotes the dome expressed by A_1 and another surface denotes the detector expressed by A_2 in fig.2.

There is a differential area element dA_1 with radiance L in the surface A_1 and another differential area element dA_2 with radiance L too in the surface A_2. The radiant power received by a differential area element dA_2 which emitted by another differential area element dA_1 can be calculated as: