Infrared Physics & Technology 73 (2015) 238–250

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Infrared radiation and stealth characteristics prediction for supersonic aircraft with uncertainty

Xiaoying Pan, Xiaojun Wang *, Ruixing Wang, Lei Wang

Institute of Solid Mechanics, Beihang University, Beijing 100191, China

HIGHLIGHTS

- An uncertain analytic process of the infrared radiation is investigated.
- The temperature, transmittance and emissivity are regarded as uncertainties.
- A proper modeling of the atmospheric transmission is established.
- The atmospheric absorption and scattering effects on radiation are considered.
- The safety assessment of the stealth performance for aircraft is conducted.

ARTICLE INFO

Article history:
Received 23 May 2015
Available online 30 September 2015

Keywords:
Infrared radiation
Atmospheric transmittance
Uncertainty analysis
Reliability assessment

ABSTRACT

The infrared radiation (IR) intensity is generally used to embody the stealth characteristics of a supersonic aircraft, which directly affects its survivability in warfare. Under such circumstances, the research on IR signature as an important branch of stealth technology is significant to overcome this threat for survivability enhancement. Considering the existence of uncertainties in material and environment, the IR intensity is indeed a range rather than a specific value. In this paper, subjected to the properties of the IR, an analytic process containing the uncertainty propagation and the reliability evaluation is investigated when taking into account that the temperature of object, the atmospheric transmittance and the spectral emissivity of materials are all regarded as uncertain parameters. For one thing, the vertex method is used to analyze and estimate the dispersion of IR intensity; for another, the safety assessment of the stealth performance for aircraft is conducted by non-probabilistic reliability analysis. For the purpose of the comparison and verification, the Monte Carlo simulation is discussed as well. The validity, usage, and efficiency of the developed methodology are demonstrated by two application examples eventually.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

With the development of the infrared tracking technology, the survival of the aircraft is confronted with a great challenge. Recently, 70–80% of aircrafts downed are due to the infrared guidance missile in regional wars. Consequently, studies on infrared radiation (IR) are of utmost importance to eliminate the threat and improve the survivability, which become the key link of stealth technology [1].

At present, a great number of researches focusing on infrared signal characteristics of aero vehicles have been published. In 1991, the NIRATAM (NATO infrared air target model) was developed by the NATO-organized RSG6, members of which research the infrared signatures of aircrafts, helicopters and anti-aircraft missiles [2]. As a computer model, it can predict the IR of an aircraft in a natural environment. Martinez [3] and Bortle [4] simulated a large commercial aircraft's infrared radiation (LCAIR) intensity of aircraft in take-off and landing states with a generalized radiometric model. Zhou [5] analyzed various kinds of infrared radiant sources from the direction of their nose aspect, and then came up with some methods to calculate the main sources of infrared radiance, which was verified later by the results of jet-powered target tests. Cline [6] described the successful validation of the F/A-22 IR signature prediction model by using in-flight IR radiometric measurements.

As for IR signal characteristics of aero vehicle fuselage skin, Mahulikar et al. [7] not only proposed an outline of a program to

* Corresponding author.

http://dx.doi.org/10.1016/j.infrared.2015.09.012
1350-4495/© 2015 Elsevier B.V. All rights reserved.

predict the infrared signature emissions from the airframe, the engine casing and the plume, but also investigated the impact of sun, sky and earth radiation on an aircraft IR signal. This research pointed out that the fuselage skin temperature has a tremendous impact on the aircraft IR radiation and those environmental factors such as the sun can result in an increase of about only 4 K in the aircraft-skin temperature, as a consequence, these factors will not be considered here. Lu and Wang [8] modeled and investigated the effects of temperature and emissivity of an aircraft fuselage skin on its IR characteristics, the result indicated that the impact of different parts of the fuselage on the whole fuselage IR signal. Pan et al. [9] studied on the impact of helicopter skin temperature on its IR characteristics, and the temperature was simulated by virtual heat sources on the fuselage skin.

Obviously, the boundary conditions and material parameters are regarded as certain variables in above researches. However, uncertainties which exist in either the internal properties or the external environments are related to the infrared stealth characteristics and should be taken into account in analysis. Rao and Mahulikar [10] pointed out that the airframe, especially the stagnation region of the aircraft nose and leading edges of wings, is aerodynamically heated at supersonic speeds [11]. Further, in order to reduce aircraft susceptibility to IR-guided threats, the applicability of rear-fuselage-skin emissivity-optimization technique is introduced. More often, on one hand, the spectral emissivity of material has certain deviation in the actual manufacturing or processing, on the other hand, the variability of the aircraft service environment and the uncertainty of environment parameters lead to the temperature of the radiation source and the average atmospheric transmittance fluctuate in a certain range. These uncertainties in the input data may propagate through the simulation model to the output data, which may deviate from the original design purpose and bring unexpected losses. Thus it has practical engineering significance to research the uncertainty evaluation of infrared radiant intensity. In the aspect of the infrared detection, Lefebvre [12] found that several sources of variability lead to a dispersion of the values likely to be observed: weather, aircraft aspect angles, aircraft type, optical properties. And then, a methodological approach is proposed, which aimed at predicting simulated infrared signature dispersion of poorly known aircraft. Although, he evaluated sensor performances and took the dispersion of the input parameters into account, the reliability assessment is not proceeded to consider the combined influence.

Based on the statements above, the temperature, the atmospheric transmittance and the spectral emissivity are considered as uncertain variables in this article. When the temperature distribution of the skin is acquired, the vertex method is used to quantify the uncertainty propagation of the input data in computational estimates, and then the interval of the IR intensity of the aircraft is obtained. Moreover, the effect of input uncertain parameters to the output is studied here. In order to measure the stealth performance, stress–strength interference theory is introduced to analyze the safety factor and reliability of computed results. Finally, Monte Carlo simulation is presented to verify the presented analytical method which has been carried out on two application examples.

The structure of the paper is as follows. The modeling of the atmospheric transmission and the computing method of IR characteristic quantities are introduced in Section 2. Section 3 proposes the calculation for IR intensity contain uncertain information and analysis process of non-probabilistic reliability. The presented methodology is demonstrated with two engineering examples in Section 4. Verification of results based on Monte Carlo simulations is also introduced. Then, some conclusions are given in Section 5.

2. Measure indices for infrared radiant intensity

2.1. The metrics of infrared radiant signature

2.1.1. Radiant exitance

Radiant exitance, embodied as M, is introduced to describe the radiation characteristics of the surface source, which is defined as the radiant energy flux transmitted by unit area of the extended source S to hemisphere space.

$$M = \lim_{\Delta t \to 0}\left(\frac{\Delta P}{\Delta A}\right) = \frac{\partial P}{\partial A} = \int_0^{\infty} M(\lambda) d\lambda \tag{1}$$

where P is the radiant power emitted by the area A of S, $M(\lambda)$ is the spectral radiant exitance which can be defined by the following equations, according to Planck's radiation law.

$$M(\lambda) = \frac{C_1}{\lambda^5}\frac{1}{e^{C_2/\lambda T} - 1} \tag{2}$$

where λ is the wave length, and the radiant exitance of specific band (λ_1, λ_2) can be expressed as:

$$M_{\lambda_1 \to \lambda_2} = \int_{\lambda_1}^{\lambda_2} M(\lambda) d\lambda = \int_{\lambda_1}^{\lambda_2} \frac{C_1}{\lambda^5}\frac{1}{e^{C_2/\lambda T} - 1} d\lambda \tag{3}$$

where C_1 and C_2 are geometrically defined as first and second radiant constant respectively, and $C_1 = 2\pi hc^2 = 3.743 \times 10^{-16}$ W m^2, $C_2 = hc/k = 1.4387 \times 10^{-2}$ m K.

2.1.2. Radiation intensity

Radiation intensity I is the radiant power which is emitted by the point radiation source in unit solid angle of a certain direction, which can be defined as:

$$I = \lim_{\Delta t \to 0}\left(\frac{\Delta P}{\Delta \Omega}\right) = \frac{\partial P}{\partial \Omega} = \left(\frac{\Delta Q}{\Delta S \partial \Omega}\right) = \frac{\partial Q}{\partial A' \partial \Omega} = \frac{\partial Q}{\partial A \partial \Omega \cos\theta} \tag{4}$$

where Q represents radiant energy, which is a function of radiant wavelength, area, solid angle and so on. A' is the projected area in the radiation direction, Ω is defined as emission solid angle and θ is the angle between the radiant source and infrared detector.

2.1.3. Radiance

Radiance L is defined as the radiant flux given off by per-unit projected area of an extended surface source within the unit solid angle in a specified direction.

$$L = \lim_{\substack{\Delta A \to 0 \\ \Delta \Omega \to 0}}\left(\frac{\Delta^2 P}{\Delta A_\theta \Delta \Omega}\right) = \frac{\partial^2 P}{\partial A_\theta \partial \Omega} = \frac{\partial^2 P}{\partial A \partial \Omega \cos\theta} \tag{5}$$

When the source of infrared radiation is surface, the relation between radiant exitance M and radiance L can be obtained as below:

$$M = \frac{dP}{dA} = \int_{2\pi Steradian} L\cos\theta d\Omega = L\int_0^{2\pi} d\varphi \int_0^{\pi/2} \cos\theta \sin\theta d\theta = \pi L \tag{6}$$

Furthermore, if the biggest size of the surface source is far less than the distance of infrared observation, this source can be considered as spot source and the relevance of radiance L to intensity I can be introduced as follows:

$$I = LA\cos\theta \tag{7}$$

2.1.4. Emissivity

The theories described above are appropriate for black body which is nonexistent in nature. Thus, some related parameters of gray body should be introduced. The emissivity ε is the ratio of the radiant exitance from radiation source to the exitance from

Download English Version:

https://daneshyari.com/en/article/1784100

Download Persian Version:

https://daneshyari.com/article/1784100

Daneshyari.com