Infrared Physics & Technology 71 (2015) 533–541

Contents lists available at ScienceDirect

Infrared Physics & Technology

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

A real-time infrared radiation imaging simulation method of aircraft skin with aerodynamic heating effect

Ni Li [a,*], Zhenhua Lv [b], Shaodan Wang [a], Guanghong Gong [a], Lei Ren [a]

[a] School of Automation Science and Electrical Engineering, Beihang University, Beijing 100191, China
[b] China Academy of Electronics and Information Technology, Beijing 100041, China

HIGHLIGHTS

- Aircraft surface was divided into panel element meshes to attach material properties.
- Established a complete mathematical model of temperature and radiation field.
- Take environmental radiation, aerodynamic heating and material properties into account.
- Comparing to the CFD simulation results, we validated the proposed aerodynamic heating simulation method.

ARTICLE INFO

Article history:
Received 11 February 2015
Available online 10 July 2015

Keywords:
Infrared radiation
Material properties
Real-time simulation
Aircraft skin

ABSTRACT

Real-time infrared radiation simulation technology can provide effective support for rapid design and evaluation of a system which integrates infrared imaging technology. Considering the aerodynamic heating effect, this paper presents a real-time infrared radiation characteristic simulation method of aircraft skin based on the panel element method, which can help to assess the infrared radiation impacts of different environment factors and materials. A 3-D model of an aircraft was established and its surface was divided into different parts and panel element meshes to attach material properties. For each mesh, its heat exchange equation is solved so as to obtain the whole skin's temperature and infrared radiation distribution. The simulation results reveal the influence of different factors on the skin surface radiation, including environmental radiation, aerodynamic heating and material properties. And the credibility and efficiency of the proposed aerodynamic heating simulation method were confirmed by comparing to the CFD simulation results.

1. Introduction

Along with the development of the infrared imaging technology, it is vastly applied in many applications in both military and civil fields, such as target detection, precision guidance, night navigation, infrared stealth and many more. There are two common ways to evaluate an infrared imaging system. One is to conduct physical experiments and tests, which can obtain images under certain meteorological environments and observation conditions. Inevitably, this method has some limitations and it is pretty expensive to implement. The other way is the simulation method. Infrared simulation methods with high fidelity can effectively overcome the restrictions of geography, weather and other environmental aspects. Thus, infrared simulation methods are widely used for the design and assessment of infrared systems and contribute to improve the cost-effectiveness.

Involving in fluid dynamics, materials science and other multi-disciplinary theories, the calculation of infrared simulation models is mainly based on the principle of thermodynamics and infrared radiation. In recent years, with the development of software industry, utilizing computer graphics and virtual reality technologies to calculate and render infrared scene has become a trend gradually [1].

The infrared radiation calculation of an aircraft is closely related with environment conditions, aerodynamic heating effects and material characteristics of its skin. As we all known, an important source of radiation is the aerodynamic heating which is produced by high-speed relative movement of aircraft and the air. And various surface materials lead to different infrared radiation properties such as emissivity, absorptivity and reflectivity capabilities, which result in diverse temperature and radiation distribution. Actually, when evaluating the impact of material properties on radiation

* Corresponding author.
E-mail address: lini@buaa.edu.cn (N. Li).

http://dx.doi.org/10.1016/j.infrared.2015.06.014
1350-4495/

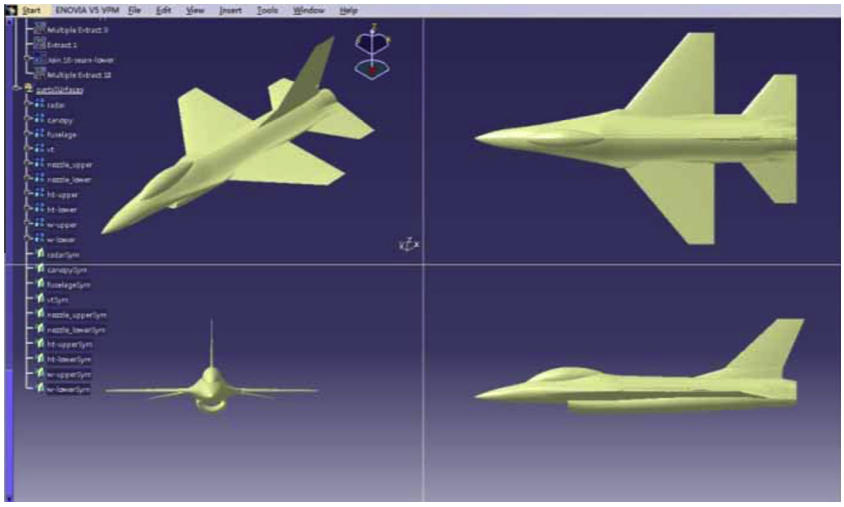

Fig. 1. 3D geometry model of an aircraft.

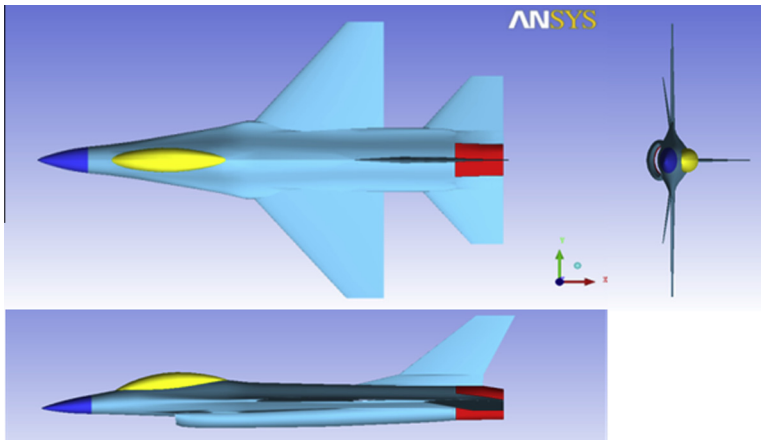

Fig. 2. Views after surface partition.

characteristics, the solving process is quite complex and time-consuming by using a fine-grained heat transfer model. To calculate the dynamic temperature distribution of a multi-material vehicle, this paper adopts a fast flow field solution which is based on the panel element method. The proposed solution can not only obtain an accurate computing result but also owns the real-time simulation and imaging abilities.

Therefore, based on material properties, a real-time infrared radiation simulation method of aircraft skin is put forward in our research. The remainder of the paper is organized as follows. In Section 2, a literature review is provided to understand the state of the art of infrared radiation simulation technology. In Section 3, we established a 3D model of an aircraft and divide the surface of the 3D model into different parts and element meshes on account of different material properties. In Section 4, the calculation of real-time radiation characteristics of different element was considered. In Section 5, a case study is provided and we analyzed the impacts of different factors and evaluate the reliability of the solution proposed in our paper. In Section 6, a summary is presented.

2. Literature review

With increasing demand for real-time infrared simulation, governments and research institutions draw more attention to physics-based infrared prediction model and provide a lot of financial support. As a result, a series of special and general infrared simulation system has been created. The Irma synthetic signature model was one of the first high resolution Infrared (IR) target and background signature models to be developed for tactical weapons application. Originally developed in 1980 by the Munitions Directorate of the Air Force Research Laboratory, the Irma model was used exclusively to generate IR scenes for smart weapons research and development [2]. Physically Reasonable Infrared Signature Model (PRISM) was developed by U.S. Army Tank -Automotive Command in 1988. PRISM is a first principles semi empirical model developed for but not limited to thermally modeling vehicles [3]. In 1990, Georgia Tech Research Institute proposed a novel infrared signature prediction model, called as Georgia Tech Signature Model (GTSIG), which calculates the temperature distribution by creating thermal meshes and difference equations [4]. Besides, Rochester Institute of Technology presented the Digital Imaging and Remote Sensing Scene Generation (DIRSIG) in 1991. This model is an integrated collection of independent first principles based on sub-models, each of which works in conjunction to produce radiance field images with high radiometric fidelity [5].

Except for governments and research institutions, some prominent visual simulation corporations have also developed and commercialized a number of infrared radiation scene rendering