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Effect of environmental radiation on the long-wave infrared signature of cruise aircraft

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ABSTRACT

In the long-wave infrared radiation band (8–12 μm), the environmental radiation greatly affects the infrared signature of aircraft. The main aim of this paper is to assess the effects of atmospheric and ground radiance on the infrared signature of a cruise aircraft flying at high altitude. Firstly, the computation method of infrared signature is presented. The reverse Monte Carlo ray tracing method is applied to evaluate the effect of environmental radiation on the infrared signature of aircraft. The MODTRAN code is used to compute the atmospheric/ground radiance and atmospheric transmittance. Then, this method is validated with experimental data. Finally, the effect of environmental radiation on infrared signature of aircraft is discussed with the consideration of atmospheric condition, flight altitude, flight speed, and the emissivity of the airframe skin. The results show that the infrared signature of the lower surface of the aircraft is sensitive to the environmental radiation whose reflection contributes more than 20% to the total radiation at Mach 0.9. Increasing flight altitude, reducing atmosphere temperature and reducing flight speed will increase the ratio of reflected environmental infrared radiation intensity to total infrared radiation intensity of the aircraft. After considering the environmental radiation, the reduction amplitude of infrared signature of the aircraft by reducing the surface emissivity is decreased. The infrared signature of the aircraft lower surface is still significant compared to environment, even though the emissivity of the aircraft surface is reduced.

1. Introduction

The infrared (IR) signature of an aircraft is one of the most important factors which affect the detection range of an IR detection system [1]. In general, the IR signature of an aircraft is mainly attributed to the following radiation sources [2]: the emission from the airframe surface and the engine hot parts, the emission from the hot plume, and the reflected environmental radiation by the surface of the aircraft. The environmental radiation, mainly includes the radiation form atmosphere, earth surface and the sun [3]. In the long-wave infrared band (8–12 μm), the dominant environmental radiations are atmospheric radiation and earth surface radiation. The relationship between environment and IR signature of a aircraft in three key ways: (1) the environment influences the surface temperature of the airframe, through radiative and convective heat transfer, and then affects the surface emission of the airframe; (2) the environment influences the amount of incident radiation on the airframe surface, in turn influence the reflected radiation from the skin; (3) the environment influences the transmission of the emitted and reflected radiation from the target to an observing sensor.

The atmospheric IR radiation is mainly attributed to the thermal emission of radiating species in atmosphere (such as CO_2, H_2O, and O_3) as well as the scattered radiation by suspended particles in the atmosphere (e.g. aerosols). The radiation of atmosphere is primarily governed by pressure, temperature, and concentration of species CO_2, H_2O, and O_3. The concentration of CO_2 is nearly constant, about 370 ppm. The concentration of H_2O decreases rapidly with the increase of altitude, and is absent above 10 km. The concentration of O_3 is prominent only at an altitude of 20–30 km. In the troposphere, the temperature and pressure decrease with the increase of altitude. In order to facilitate the calculation of the atmospheric radiance and transmissivity, some typical atmospheric IR radiation models are developed, such as 1976 US Standard model, Mid-latitude Summer (45 degrees North, July) model, Mid-latitude Winter (45 degrees North, January) model, etc.

Some simple empirical models, such as Bliss model [4], Kimball model [5], Awanou model [6] and Berger model [7,8], can be used to calculate the atmospheric infrared radiation. However, these models usually are used to calculate the atmospheric radiation near ground, and may not be suitable for the calculation at

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high altitude. In addition to those models, the LOWTRAN/MODTRAN code [9] are two widely used tools to accurate calculate the environmental radiation and the propagation of infrared radiation through the atmosphere. They are comprehensive empirical-based programs based on band models of molecular absorption, so they have improved accuracy. For the simulation of the emission from the earth surface, the infrared radiation is treated as a function of several parameters, e.g. vegetation, temperature, humidity, type of soil and rock [10]. Most surfaces characterizing the earth are predominantly diffuse and behave as grey bodies with high emissivity ε. Therefore, the earth surface emission could be simulated by using Lambert model [11].

There are a lot of valuable studies about the aircraft IR signature in the long-wave band. Coiro [1] upgraded the CRIRA (Calcul du Rayonnement InfraRouge des Avions) code with a global illumination model and validated it on a Boeing 737 airplane. The global illumination model uses a Monte Carlo Ray Tracer (MCRT) to model the reflection of the natural environment radiation on the aircraft, the emissions and reflections of the airplane on itself. Comparing with experimental data, the accuracy of thermal image was improved with this technique. However, detailed analysis of the effect of environmental infrared radiation on the IR signature of the aircraft was not provided. Harkiss [12] investigated the effect of Bi-directional Reflectance Distribution Function (BRDF) of the aircraft surface and the number of reflection bounces on the IR signature of a large commercial aircraft at takeoff and landing. Li et al. [13] developed a real-time aircraft infrared imaging simulation code, which involves temperature model, infrared radiation model of zero-distance, atmospheric transfer model and infrared imaging system effect model. However, the reflections between different regional surface elements of the airframe surface, and the reflections inside the nozzle cavity seem not to be included in the computation. Mahulikar et al. [10] and Rao et al. [14] investigated the effect of atmospheric radiance on the IR signature of an aircraft flying at altitude of 5 km by using the Berger model [7]. The results showed that the atmospheric radiation plays a significant role to determine the IR signature of the aircraft. Lu et al. [15] investigated the infrared radiation characteristics of the aircraft surface with the computational fluid dynamics (CFD) and the Reverse Monte Carlo (RMC) method. However, the environmental radiation was not considered in the study.

The IR signature of aircraft strongly depends on the flight conditions, the environment properties, the detection aspect angles, and the spectral bands, etc. It seems that, in the literatures, the investigation of the effect of environmental radiation on the IR signature of aircraft is insufficient, especially for an aircraft cruising at high altitude. The main purpose of this paper is to assess the effect of infrared radiation of atmosphere and earth ground on the long-wave band IR signature of a cruise aircraft at high altitude. The effects of flight speeds (Mach 0.9, 1.2 and 1.5), flight altitudes (7 km and 11 km), seasons (winter and summer) as well as the emissivity of the airframe surface on the IR signature are studied in present work.

2. The method of IR signature computation

2.1. Computation procedure of aircraft infrared radiation

The main radiation sources of long wave band IR signature of an aircraft are as follows: (1) the surface of the aircraft; (2) the intake cavity, which is composed of intake duct and the first stage of the low-pressure compressor of the engine; (3) the exhaust cavity, which is composed of the last stage of the turbine and all components downstream it, e.g. mixer, central body, flame holders, afterburner and nozzle, et al.; (4) the exhaust hot gases of the engine. The surface of the aircraft not only emits energy due to it's temperature above absolute zero degree, but also reflects environmental radiation (such as atmosphere, earth surface and sun). The radiation from sun will also rise the temperature of the airframe surface, and in turn increases the IR signature of an aircraft. All of these factors should be taken into account to calculate the long-wave band IR signature of an aircraft. However, this paper only concentrates on, among various environmental radiations, atmospheric and earth ground radiation. Fig. 1 presents the above-mentioned main sources to the IR signature of an aircraft.

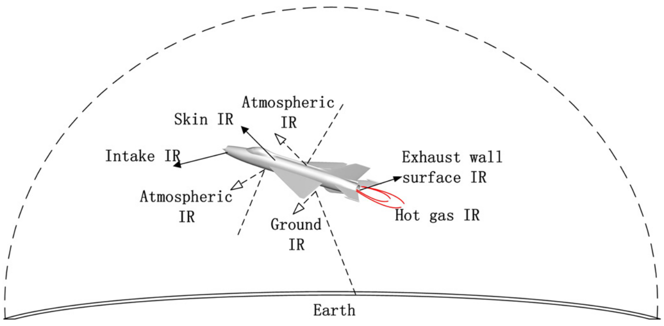

Fig. 1. The main contributors to the long wave IR signature of an aircraft.

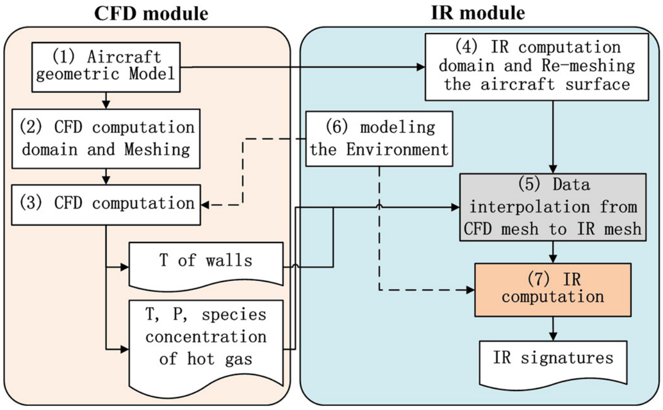

Fig. 2. Computation procedure of aircraft infrared radiation.

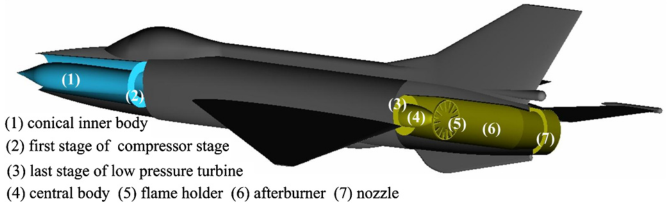

Fig. 3. A side view of the aircraft.

Fig. 2 shows the computation procedure of aircraft infrared radiation, which consists of two modules, CFD module and IR module. The computation procedure is as follows: (1) establishing the aircraft geometric model, (2) meshing the CFD computation domain in facet and volume elements, (3) computing the flow field and the temperature field, (4) meshing the IR computation domain and re-meshing the surface in facet elements, (5) interpolating the CFD data (including the temperature of walls and hot gas flow, as well as the pressure and species concentration of the hot gas flow) to the IR computation mesh, (6) modeling the natural environment, and (7) computing the IR signatures of the aircraft.

2.2. Geometric model

The aircraft geometry model consists of intake cavity, fuselage surface, and engine exhaust cavity, as shown in Fig. 3. The intake