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Effects of rotor downwash on exhaust plume flow and helicopter infrared signature

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HIGHLIGHTS

- Illustrate effects of rotor downwash and exhaust direction on plume flow field.
- Modeling helicopter infrared signature taking into consideration of rotor downwash action.
- Assessing different orientation of exhaust plume on helicopter infrared intensity.
- Oblique-turned exhaust mode is reasonable for helicopter infrared suppressor.
- Rotor downwash has a complicated influence on helicopter infrared radiation distribution.

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ABSTRACT

The effects of rotor downwash and exhaust direction on plume flow field, rear-fuselage temperature distribution and helicopter infrared signature were numerically investigated. The internal flow inside IR suppressor originated from engine exhaust nozzle and the external flow around helicopter airframe originated from rotor downwash were computed in a coupled mode to determine the temperature distributions on the helicopter skin and in the exhaust plume. Based on the skin and plume temperature distributions, a forward–backward ray-tracing method was used to calculate the infrared radiation intensity from the helicopter with a narrow-band model. The results show that the exhaust plume takes on strong downwards deflection to the rear-fuselage, as well as to the rotor rotational direction under the action of rotor downwash. The rotor downwash has a complicated influence on the infrared radiation distribution of helicopter. It is benefit for reducing the infrared radiation intensity when the exhaust is ejected in oblique-turned or lateral-turned mode. While for the up-turned exhaust mode, the exhaust plume could heating the helicopter rear-fuselage and the infrared radiation intensity may be enhanced under the action of downwash.

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1. Introduction

Helicopters are subjected to serious threats from radio, infrared, visual, and aural detection in a tactical warfare due to their low-attitude and low-speed fight missions. Among these threats, infrared (IR) detection and tracking are regarded as more crucial for the survivability of helicopters. Firstly, passive detection and tracking by infrared signature seeking missiles are tactically superior to active ones for a comparable detection range [1,2]. Furthermore, the rapid advances in processor and detector array technology make the infrared-guided missiles more effective. On the other hand, with the increase of the ratio of power to weight for turbo-shaft engines mainly equipped in helicopters, the exhaust temperature increases tremendously, resulting in an infrared signature augment intensively. Consequently, infrared signature suppression is an important issue associated with helicopter susceptibility.

The sources of infrared signature in a helicopter and their classification are shown in Fig. 1. The important internal infrared sources include plume emission and surface emissions from the following: (a) engine hot parts or tailpipe, (b) exhaust plume, (c) airframe skin heated by the engine and plume, and (d) reflected skyshine, earthshine and sunshine from helicopter fuselage. Among these infrared sources, the engine tailpipe is major and reliable source for infrared signature level in the 3–5 μm band because of large amount of heat produced by combustion inside the gas turbine engine. Simultaneously, helicopter rear-fuselage

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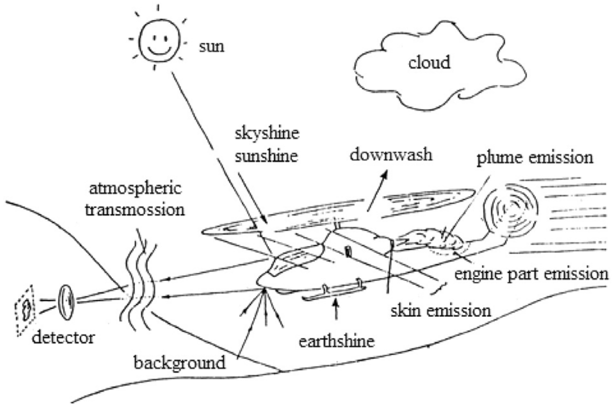

Fig. 1. Sources of IR radiance from helicopter and their classification.

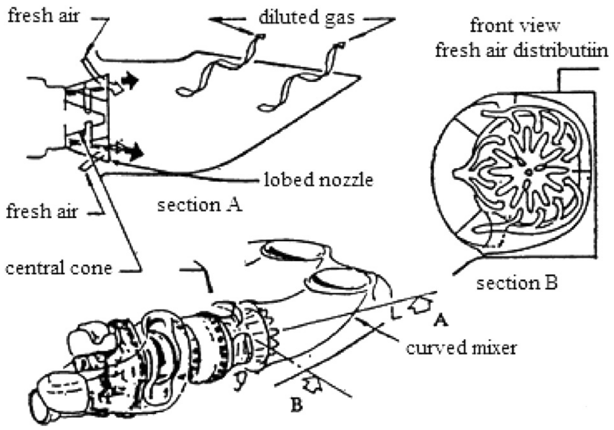

Fig. 2. Schematic of lobed mixer-ejector IRS [6].

skin is always heated by exhaust flow from the embedded engine. Though the spectral radiance of rear-fuselage is less than the tailpipe, infrared emission from the rear-fuselage is important to total infrared signature level in the 3–5 μm band and the 8–14 μm band, especially in the 8–14 μm band. Again, the solid angle subtended by the rear-fuselage skin is an order of magnitude larger than the tailpipe.

A lot of studies have covered the development of helicopter infrared suppressors and IR prediction models. The first generation of infrared suppressors typically features an up-turned nozzle shielded from a direct view by an insulating cowl. It is generally adaptable for opposing infrared-guided missiles working at the 1.7–2.8 μm band. While this principle holds for radiation of any wavelength, new warheads operating in the 3–5 μm band have the additional capability of locking on weaker signals emitted at relatively lower temperatures. The exhaust plume radiates a detectable amount of energy due to discrete rays in the carbon dioxide spectrum of 3–5 μm band. Diluting the engine plume with cold ambient air decreases CO_2 concentration and temperature and therefore reduces the target detectability. This is most conveniently achieved by means of a passive ejector. Based on this mechanism, several different types of infrared suppressors (IRS) for helicopter engines were developed in recent decades, such as Cascaded Ejector-Based IRS, Black Hole Ocarina (BHO) IRS, Lobed Mixer-Ejector IRS, etc [3,4]. Basically, an ejector is composed of: (a) a primary nozzle which injects hot primary flow into the mixing duct, (b) an intake system which collects, directs, and accelerates ambient air (or secondary flow) up to mixing duct inlet, (c) a mixing duct or mixer inside which momentum is transferred from primary to secondary stream and where both fluids are mixed, and (d) a diffuser where the residual kinetic energy of the mixed flow is partially recovered and transformed into pressure. In short efficient ejector systems, the primary nozzle plays an important role on the pumping and mixing capacities. The lobed nozzle is illustrated to be one of the best choices [5–8]. The alternating misalignment of lobed chutes causes streamwise vortices which rapidly mix the primary and secondary flow together. The rapid internal mixing of co-flowing streams lowers static pressure at the nozzle exit and results in pumping capacity augmentation. The lobed mixer-ejector IRS was firstly adopted by the Turbomeca Dauphin SA365C, as seen in Fig. 2. Evaluation tests showed that this kind of infrared suppressors was of high dilution, low turbine backpressure, low aerodynamic drag, compactness, and light weight. It reduced infrared signal-to-noise ratio in the 3–5 μm band by 39 dB, with acceptable power loss limited in 2.5% at hover IGE power [3]. Zhang et al. [9–13] made a series of fundamental studies on lobed mixer-ejector IRS. The effects of ambient air pumping-mixing and heat shelter-insulation on decreasing the target infrared signature were concluded. (1) Ambient air pumping-mixing plays a dual role for reducing the exhaust temperature and mixing duct temperature. This role is more obvious in the case of larger mass flow ratio of secondary flow to primary flow. (2) Sheltering from the hot mixing duct makes the shelter surface temperature close to ambient temperature when the sheltering distance is greater than 20 mm and (3) Ambient air pumping-mixing contributes about 85% suppression for the total target infrared radiation intensity and heat shelter-insulation contributes about 10% suppression again.

As regard as modeling of infrared signature is concerned, all major research establishments have developed their own models for prediction of infrared signature level (IRSL) from IR targets. These models can be grouped into three categories: (a) models for prediction of IR emissions from plume, power-plant, and complete aircraft, etc., (b) models for obtaining atmospheric infrared transmissivity and radiance, and (c) models for IRSL processing and generating spatial scene map, infrared searching and tracking, etc. [14]. A simple descriptive model for plume IR radiation estimation was firstly given by Decher [15] and Chu et al. [16]. The effects of plume core length, spectral optical depth, and nozzle size of high aspect ratio nozzles were analyzed on IR signature characteristics of the turbofan engine. A standardized infrared radiation model (SIRRM) code was developed under JANNAF (Joint Army Navy NASA Air Force) project to predict IR radiation from missile and aircraft plumes [17]. Mahulikar and Rao made a series of investigations on predicting infrared signature for various infrared targets, e.g. exhaust plume, exhaust nozzle and aircraft [18–22]. An outline of a program was presented to predict infrared signature emissions from the airframe, engine casing and plume as well as their attenuation due to atmosphere intervention. In addition, a multimode thermal model was developed for predicting the rear fuselage skin temperature, considering the variations in transport and flow properties with temperature, and effect of cross-sectional area variation, heat transfer and skin friction. They also made some studies taking into account of sunshine, skyshine, and earthshine for aircraft infrared detection [23–25].

For helicopter, the main rotor downwash (as seen in Fig. 1) has a unique feature affecting temperature distributions on the fuselage skin and in the exhaust plume. Firstly, the exhaust plume flow is seriously affected by the rotor downwash flow owing to its mixing action. Moreover, helicopter rear-fuselage surfaces could be heated by exhaust plume under the rotor downwash. In order to understand the effects of rotor downwash on plume temperature and ejecting capacity of helicopter exhaust systems, Wang et al. [26], Zhu and Huang [27] conducted experimental investigations

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