Influence of color coatings on aircraft surface ice detection based on multi-wavelength imaging*

ZHUGE Jing-chang (诸葛晶昌)[1]**, **YU Zhi-jing** (于之靖)[1], **GAO Jian-shu** (高建树)[2], **and ZHENG Da-chuan** (郑大川)[1]

1. College of Electronic Information and Automation, Civil Aviation University of China, Tianjin 300300, China

2. Airport College, Civil Aviation University of China, Tianjin 300300, China

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In this paper, a simple aircraft surface ice detection system is proposed based on multi-wavelength imaging. Its feasibility is proved by the experimental results. The influence of color coatings of aircraft surface is investigated. The results show that the ice area can be clearly distinguished from the red, white, gray and blue coatings painted aluminum plates. Due to the strong absorption, not enough signals can be detected for the black coatings. Thus, a deep research is needed. Even though, the results of this paper are helpful to the development of aircraft surface ice detection.

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Aircraft surface ice is one of the factors that strongly influence the safety of aircraft[1-3]. Correspondingly, deicing methods, such as ultrasonic, mechanical, electro-thermal and infrared optical technologies, have been developed. Among these methods, the infrared optical deicing technology is very promising because it is with low cost, high efficiency and environmental-friendly property[4,5]. Whether the aircraft is in flight or on ground, the ice detection is a primary procedure, so countries all over the world have started the aircraft surface ice detection research[6-10].

At present, a large number of ice detection methods are based on vision and touch. However, these methods are not only laborious, but also easy to cause error detection. Thus, a more objective method is on demand. In China, the fiber-optic icing sensor, jointly developed by Huazhong University of Science and Technology and Civil Aviation University of China, can not only detect the area of ice, but also obtain reliable information about the thickness[11,12]. The IceHawk developed by Goodrich Aerospace, and the remote on-ground ice detection system (ROGIDS) developed by MacDonald Dettwiler and Associates (Canada) can be used for automatic detection of ice[13]. The IceHawk system uses a calibrated laser source to illuminate a small point on the detected surface and scans with a linearly polarized light beam. The detection efficiency is low. The ROGIDS uses the near infrared multi-spectrum detection system. Due to the use of the imaging technology, the detection efficiency is high. It has the potential to become the most promising method[14-16]. But the influence of aircraft coatings is not mentioned.

Various investigations of the aircraft surface ice detection and infrared radiation characteristics of aircraft have been reported[17-21]. However, the influence of different aircraft coatings on surface ice detection is rarely reported. The coatings can not only make the aircraft colorful, but also protect the aircraft from corrosion. The spectral properties of aircraft coatings have been studied by Korth et al[22,23]. Coatings with different colors have different spectral properties, which will change the optical properties of ice on the aircraft surface. Thus, the influence of the aircraft surface coatings with different colors on the ice detection is worth investigating. In this study, by using an infrared camera to collect multi-wavelength images, a simple and effective aircraft surface ice detection system is proposed.

Five kinds of coatings with different colors (red, black, white, gray and blue) are chosen in this study. They are commonly made of protective enamels (Type: BMS10-60). First, the aluminum alloy plates were painted by professionals, and the procedure followed the national standards. Taking the uncoated plate into account, we have totally six samples.

The normalized reflectance spectra (relative to the reflectivity at 1.10 μm) of ice and water in the near infrared range are illustrated in Fig.1. Define a parameter C as

$$C = \frac{R_L - R_U}{R_L + R_U}, \qquad (1)$$

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** E-mail:12315414@qq.com

where R_L and R_U are the reflectivities at the wavelengths of 1.16 μm and 1.26 μm, respectively. It can be found that for ice, C is a positive value, while for water it is a negative value.

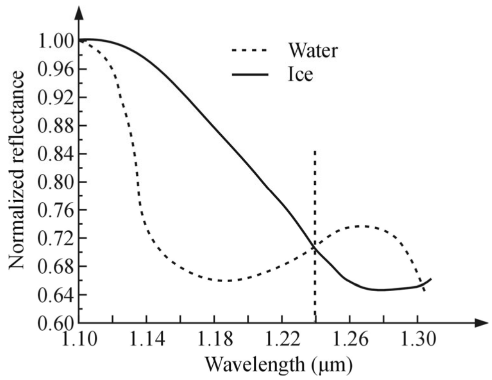


Fig.1 The normalized reflectance spectra of ice and water

When there is a substrate under the ice, the influence caused by the substrate should be considered. According to the Kubelka-Munk's dual flux theory on the film-covered substrate, the relative reflectance ratio is defined as

$$\rho = \frac{1-\rho_g[a-b\coth(bSX)]}{a-\rho_g+b\coth(bSX)}, \tag{2}$$

where $a=1+(K/S)$, $b=(a^2-1)^{1/2}$, and coth(bSX) is a hyperbolic cotangent function. From Eq.(2), the relative reflectance ratio of opaque or semitransparent medium is related to absorption coefficient K, scattering coefficient S, film thickness X, and the reflectance ratio of the substrate ρ_g.

To obtain the reflectivity from the sample surface, a multi-wavelength imaging system is developed, as shown in Fig.2. The light from xenon lamp (CTTH-150 W, CrownTech) provides the near infrared illumination. The infrared camera (c0812-OBSWIR) is applied to take photos of the samples. The camera can provide a photo size of 320×256 pixels. A conventional camera is applied to locate the samples. Band filters (1.10 μm, 1.16 μm, 1.26 μm, 1.28 μm) let the narrow band light through and block other wavelengths of light into the infrared camera. By using the proposed system, we can obtain the photos of all the six samples at different light irradiation intensities, in which the gray value can represent the reflectance.

To eliminate the influence of the aluminum plate, we calculate the reflectivities of the aluminum plate without ice. The reflectivities at wavelengths of 1.10 μm, 1.16 μm, 1.26 μm and 1.28 μm are 0.871 0, 0.877 6, 0.888 6 and 0.890 8, respectively. Results show that at different wavelengths, the reflectivities are close to each other, so the influence can be ignored.

Fig.3(a) and (b) show the gray values of the six plates without ice. Fig.3(c) and (d) show the gray values of the

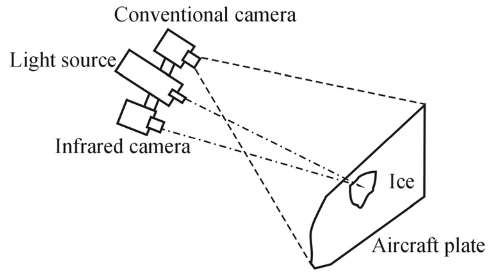
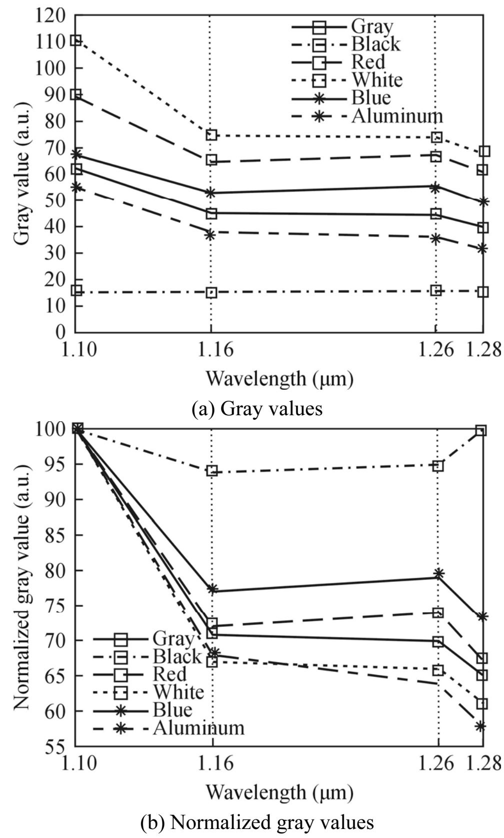
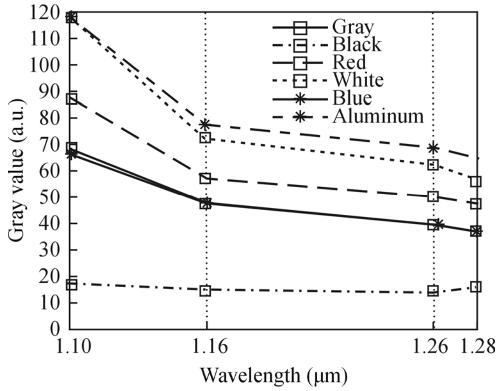


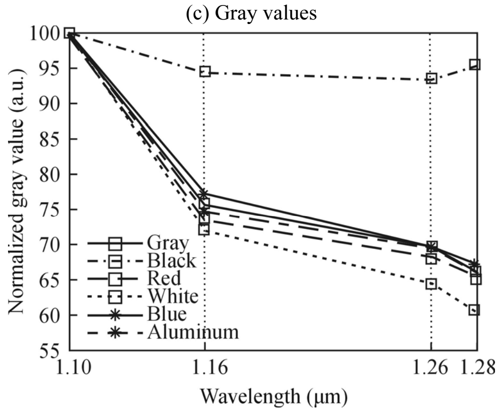
Fig.2 The schematic diagram of the experimental apparatus

six plates covered by ice, and the C values are also calculated. We can draw the following conclusions. The absolute reflectivities are different from each other, which means that the spectral properties are different for different color coatings. The ascending order of the gray valves of the plates without ice is black, aluminum, gray, blue, red and white, while that of the plates with ice is black, gray, blue, red, white and aluminum. We find that for the aluminum plate without ice, its gray value is low. However, the one with ice has the highest value. Covered by ice, the C values of gray, black, red, white, blue and aluminum plates are 0.063 4, 0.006 4, 0.066 0, 0.089 0, 0.075 9 and 0.052 5, respectively, while without ice, the C values of those are 0.005 4, −0.003 2, −0.012 7, 0.004 6, −0.014 3 and 0.026 7, respectively. It is found that the samples with ice normally have a larger C value. The black one absorbs too much light, and not enough signals can be detected, so the C value for the black one cannot be used to identify the ice area.





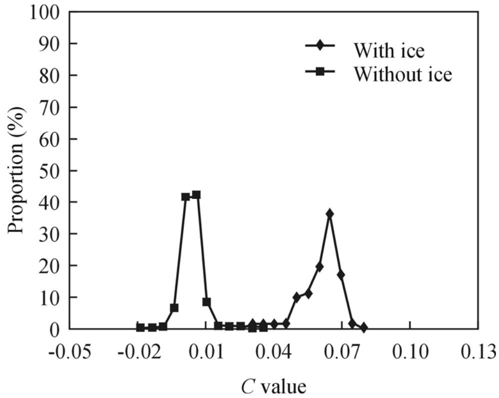
(c) Gray values



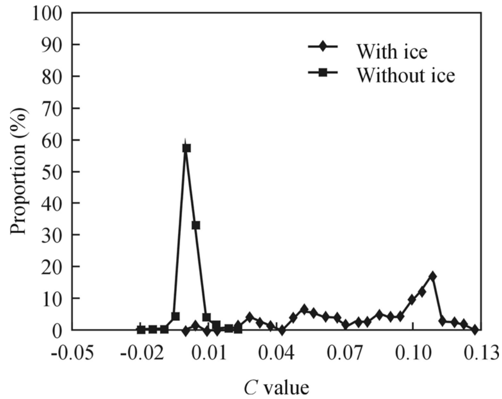
(d) Normalized gray values

Fig.3 The gray values of six plates (a,b) without and (c,d) with ice

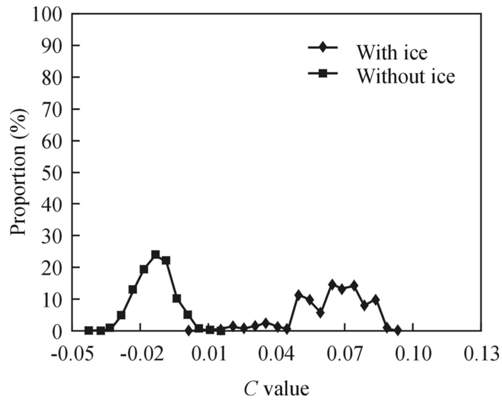
Mostly, the calculated *C* values are not constant as shown in Fig.4. For the gray, white, red, blue, black and aluminum samples, the existence of ice normally leads to a larger *C* value, as shown in Fig.4(a)—(d). Thus the *C* values can be applied to distinguish the ice area. But for the black sample, the absorption of the coating strongly influences the measurement of reflectivity, as shown in Fig.4(e). The two peaks are so close that the ice area cannot be distinguished. From Fig.4(f), we can find that the two curves are too close to each other, so the *C* values of the aluminum sample are unable to be used for ice detection. Thus, a further investigation for the ice detection on the black coated and uncoated aluminum plates is needed.



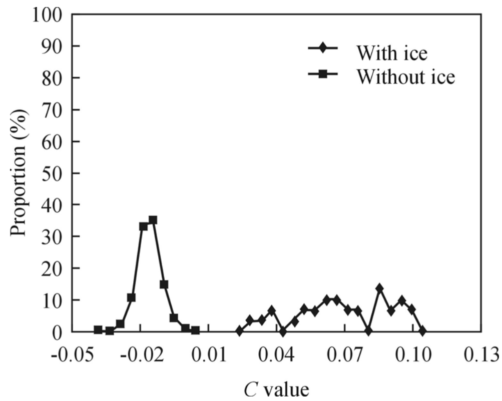
(a) Gray plate



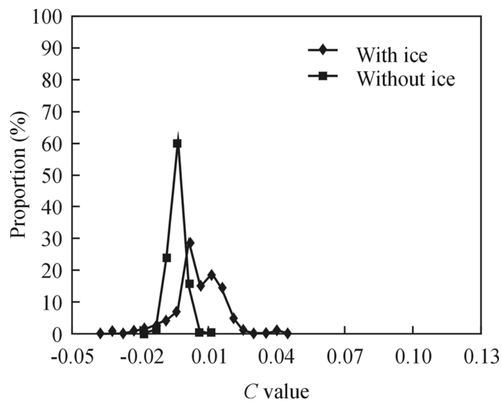
(b) White plate



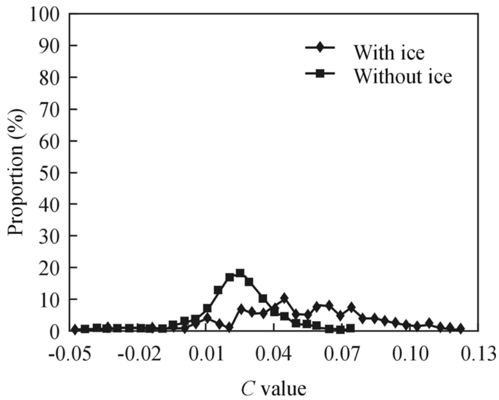
(c) Red plate



(d) Blue plate



(e) Black plate



(f) Aluminum plate

Fig.4 Comparison of *C* values distributions of six plates with and without ice

A simple aircraft surface ice detection method based on multi-wavelength imaging system is proposed. The feasibility of the method is proved by the experimental results. The influence caused by different color coatings is investigated. For most coatings, the method is effective. For black coating, a deep research is needed. Even though, the results of this paper can be helpful to the development of aircraft surface ice detection system.

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