

INVESTIGATION OF ICE SHAPE CHARACTERISTICS FOR LOW-SPEED HIGH ALTITUDE LONG ENDURANCE AIRCRAFT IN ICING CONDITIONS

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Introduction

Recently, there has been a growing interest in a high altitude long endurance (HALE) aircraft not only among aircraft manufacturers but also among information technology (IT) companies. The representative leading IT companies: Google and Facebook, have acquired a firm developing a HALE, which could serve as a node to provide internet connectivity from the stratosphere. For the purpose of the internet connectivity, the cost of the HALE for acquisition and operation is cheaper than that of the satellite.

The operating altitude of the HALE is about 10–15 km. The range of altitude corresponds to the stratosphere. Meteorological phenomena such as precipitation do not occur in the stratosphere. Aircraft icing that is the major cause of the weather-related accident(s) also does not happen in there, since there has no water droplet which is the cause of precipitation and icing phenomenon. However, the HALE can encounter the icing conditions when it passes through the atmosphere for climbing and descending stages. The exposed time increases due to low rate of climb and descent. In spite of the utility of the HALE, icing phenomenon has restricted the task performance ability and all-weather capability. However, the HALE is the novel conceptual platform of aircraft; therefore, it has a short history for the design, development, and operation compare to commercial aircrafts. The majority of studies have focused on the commercial aircrafts to analyze the aerodynamic performance in icing conditions.

The prediction of ice accretions shapes should be preceded to evaluation of the aerodynamic performance for the ice accumulated HALE. As a representative HALE icing research, Iya, and Cook [1] investigated the ice accretion shapes on a typical HALE airfoil by 2D ice accretion code, LEWICE. They found that it took over 100 hours to sublimate the whole ice on the surface without anti/de-icing device. Their search suggested operating strategy of a HALE, but had limitation for the guideline to the HALE operators.

To this end, this study is aimed to predict the ice accretion shapes and to comprehend the aerodynamic performance of the ice accumulated typical 3D HALE with various icing conditions.

Numerical methods

The icing analysis package that was developed in this study is composed of four different modules – 1) flow analysis module (rhoPimpleFoam), 2) droplet-trajectory calculation module, 3) thermodynamic module [2], and 4) surface grid-regeneration module. Each module is considered for generic 3D geometries. All of the modules were developed on the same platform, OpenFOAM-2.2.0, rendering the user inconvenience minimal with respect to the data transfer between the modules.

Although real icing phenomena are unpredictable by nature, in this study, because of the limited computational resources, quasi-steady flows are assumed. Droplet trajectories based on the velocity vectors obtained from the converged flow-field solutions are computed by Eulerian approach. Then, using these results, the thermodynamic analyse based on water film model [2] are performed. The ice shapes are deliberately determined from the evaluation of the ice mass accreted on the surface.

Results

The calculated HALE is named EAV-2+ which is developed by KARI (Koran Aerospace Research Institute). It is powered by the solar cell located on the upper surface of main wings. The longest operation hour for this HALE was 25 hours. The chord length is 0.5m, and the span length is 11m. Two propellers are located at $y/S=20\%$ of each wing, but the propellers are ignored in the flow solver and icing solver.

The ice accretion occurs for the climbing stage. The ambient conditions such as humidity, temperature, density, and pressure change significantly with increases in elevation. The unsteady calculation should be considered the ambient conditions. However, it is impossible due to the computational burden. Thus, it is applied one shot method by assuming quasi-steady state. The operation altitude of the HALE is 10 km, but the representative ambient condition is considered as 5km condition. The high LWC (Liquid Water Contents) and high temperature condition is chosen from the Federal Aviation Regulations, Part 25 Appendix C, because the degradation of aerodynamic performance is high in glaze icing condition. The corresponding flow and ambient meteorological conditions are summarized in Table 1.

Figure 1 shows the ice accretion shape on the HALE surface. Yellow means the accumulated ice. As can be seen in the fig. 1, most of the ice was accumulated on the front region of HALE such as fuselage nose, and leading edge of wings.

Although the icing condition which glaze ice and ice horn are formed is chosen, the ice shape develops into the rime ice shape.

Table 1: Title of table

α [°]	T_∞ [K]	V_∞ [m/s]	LWC [g/m ³]	MVD [μ m]	Time [h]
0	262	7.6	0.8	27.5	2

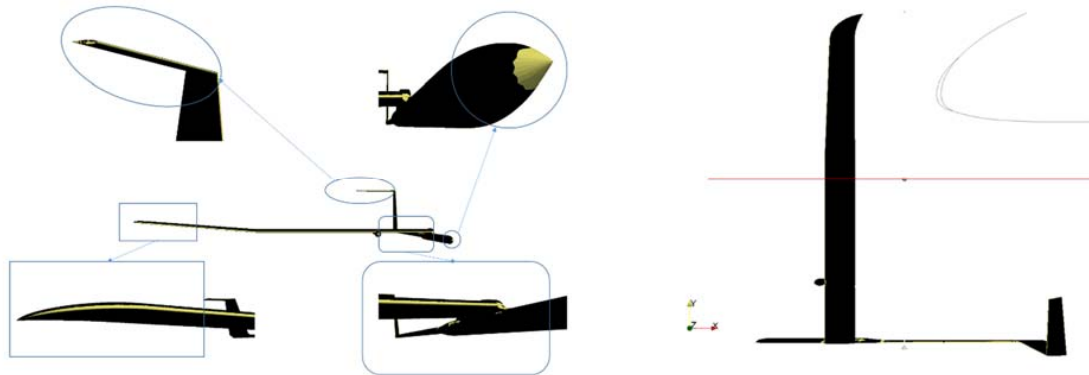


Figure 1 : The ice accretion shape on the HALE and sectional ice shape of main wing at y/S=50%.

The interesting result can be explained by following equation:

$$K = \frac{\rho_w V_\infty MVD^2}{18\mu c} \quad (1)$$

The droplet-inertia (K) that is the similarity parameter for the droplet behavior, as shown in Eq. 1. As the freestream velocity decreases, the droplet-inertia parameter also declines. Due to the low freestream velocity, the droplet is sensitive to the change of the flow field. The droplet path lines become like a streamline of flow fields. The droplets tend to avoid the surface without colliding with the surface, resulting in a substantial reduction of the impinging mass. The remaining water which does not freeze on the surface flows along the surface. It is called runback water. The runback water freezes into ice where the convective heat transfer is high region. Consequently, it became the ice horn. However, there is no or less remaining water on the HALE surface because of low flight speed. The rime ice shape is similar to the airfoil surface. It can be expected that the degradation of aerodynamic performance would not be serious. Up to now, the ice accretion shapes are extracted with various icing conditions. The tendency of aerodynamic performance of ice accumulated HALE, and the operation limits will be presented in the workshop.

Conclusion

In the present study, an up-to-date numerical analysis program was developed for 3D ice-accretion shapes, and applied it to predict the ice shape on the HALE. The droplet trajectories based on the Eulerian approach were calculated, enabling us to determine the collection efficiency in separate regions. For the thermodynamic analysis, the thin-water film mode was introduced. Even in the glaze icing condition, the developed solver yields the rime ice shape on the HALE surface. The imping water is not enough to make runback water and the ice horn due to low flight speed. As a result, it is expected that the operation limits of HALE will be extended.

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