A STUDY ON THE POSITIONING OF ICE SENSOR FOR ICING AIRWORTHINESS OF MILITARY HELICOPTER

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Abstract- The measurement of icing condition needs to be conducted accurately for the anti/de-icing system of aircraft. Therefore, the ice detector which measures the icing condition of the atmosphere requires careful positioning. This can be done by avoiding such effects: backwash due to aircraft configuration, downwash of rotor and intervention of doors and other equipment. In order to do this, a research to discover the optimal position through analyzing the effects of installment of the ice detector and taking into consideration possible installing area is required. This research is conducted through three-dimensional computational analysis by considering the effects of fuselage configuration and the downwash of rotor. This research evaluates the original position of the ice detector by comparing the water droplet contents of the atmosphere in each flight and icing conditions and the water droplet contents in the ice sensor position. Through the results of the analysis, the researchers drew an improvement position.

Keywords- Icing airworthiness, Liquid Water Content, Mean Volume Diameter, Military helicopter

I. INTRODUCTION

An aircraft flying in the air is characterized by speed, economics, safety and efficiency, and especially, if an accident occurs during a flight, casualties of all the crew may occur, so aircraft safety is very important. Of the causes, climate is one of the most important factors, which takes up 20.1% of the total aircraft accidents that occurred in the United States between 2003 and 2007, and icing causes failure to the flight and causes fatal aircraft accidents.
Of them, by the characteristics of mission, all-weather operation is specified as a requirement for military helicopter, and accordingly, if a helicopter is exposed to an icing condition, icing may be caused by super-cooling water spot in the main rotor or collision of cloud particles.

This icing phenomenon scatters air flow in the main rotor, and it collapses the balance of the helicopter with an increase in drag and reduction in lift and disturbs the operation of the helicopter, which may bring about a fatal outcome. Thus, for military helicopter to secure operational capability in icing conditions, it is necessary to remove icing and install a device preventing icing, and icing airworthiness is required.

Various devices required for the operation of military helicopter in icing conditions consist of an ice sensor measuring icing, an de-icing device and anti-icing installed in the engine, rotor, speedometer and rotor blade, and especially, since the ice sensor is a device recognizing the status of icing in the air, the position of installation is very important. Therefore, this study conducted a data processing analysis of the flow field with 3-D fuselage shape in order to judge icing conditions of the flow field in the ice sensor position and selected the optimum position of the ice sensor using that.

II. SYSTEM CONFIGURATION AND COSIDERATIONS

2.1 Materials and Procedures

The diagram of devices to prevent and remove icing with the main rotor of a helicopter is illustrated in Fig. 1, and the main devices consist of an OAT sensor, ice sensor, controller and heating mat. Icing conditions provided from the OAT sensor and ice sensor are provided for the controller and the heating cycle operates according to the given environment.

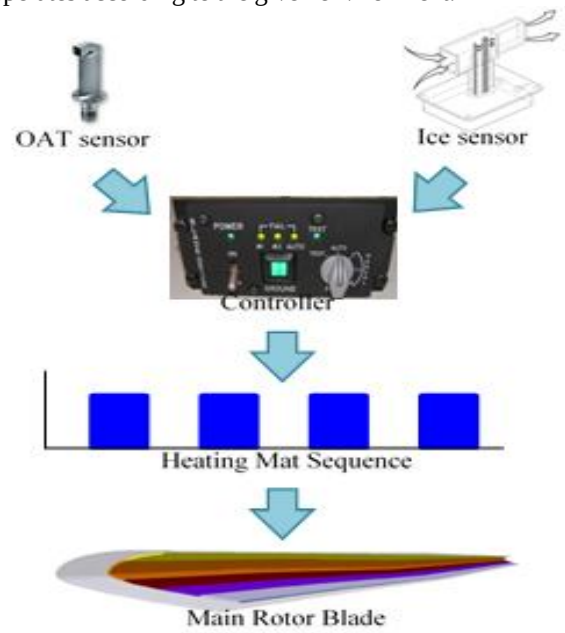


Fig.1. Configuration of anti / de-icing equipment for rotor blade.

2.2 Consideration in Positioning Icing Sensor

If wrong information is delivered to the controller from the ice sensor, the functions of the blade de-icing or anti-icing are not achieved normally, so flight safety

cannot be secured. Thus, it is very important to select a position so that the ice sensor can measure icing conditions in the air as accurately as possible. Aircraft ice protection, Appendix of the U.S. Federal Aviation Administration requires the positioning standard like Table 1.

Table 1. Reference of installation location.

· Position it in front of the helicopter, in which there is less deviation of the air flow according to the shape of the helicopter and for the most practical sensing.
· Avoid positioning in the back of external fixtures disturbing the air flow.
· Separate from the fuselage to avoid being measured in the fuselage Interface.
· Allow continuous sensing in hovering flight.
· Install at the position with the smallest impact of the rotor wind.

To secure the ice sensor's accurate measurement, an analysis of impact should be conducted, considering the following matters with the selection of critical icing conditions.

(1) Flight condition: Velocity, Angle Of Attack (AOA), Angle of Sideslip (AOS);
(2) Aircraft shape: Rotor down wash, helicopter nose shape; and
(3) Icing conditions: Liquid Water Content (LWC), air temperature, Median Volume Diameter (MVD).

In addition, since the ice sensor is a device measuring LWC by sampling ice water droplets, because of aircraft flight condition and outer shape, if there is an object disturbing the trajectory of the ice water droplets, the ice water droplets behind the object are sharply reduced and have a trajectory different from the air flow, which is called shadow area. Thus, the ice sensor should avoid the shadow area occurring because of the aircraft flight condition and outer shape.
For an analysis of suitability of the position of this ice sensor, the suitability can be known through the ratio of local LWC (LWC/LWC∞) of the air LWC_{∞} and ice sensor position, so it is necessary to conduct an analysis of the trajectory of the surrounding ice water droplets during the flight.

III. SELECTION OF ANALYSIS TECHNIQUES AND CONDITIONS

3.1 Device Data Processing Analysis Modeling and Procedures

For an analysis of ice sensor positioning, 3-D modeling of the aircraft shape is necessary, and the impact could be simulated by the interference of down wash and fuselage of the main rotor. The simulation of the down wash of the main rotor was implemented, considering swirling in the actuator disk method, which is commonly often used, and Fig. 2 shows the shapes and elements for modeling the fuselage and rotor in 3-D. For the implementation of the ice sensor, an ice sensor grid was produced like Fig. 3, and the ice sensor was positioned to the right of the helicopter like Fig. 4, and for an analysis of the accurate flow field, the surrounding grid was made dense.
The procedure of analysis were as follows: In Step 1, modeling and grid were produced using CAD as shown in Fig. 5; in Step 2, the trajectory of the flow field and icing droplets were analyzed, using commercial CFD software, FENSAP-ICE; and in Step 3, an analysis was conducted with the results through post-processing. The grid used at this time was a tetrahedral prism layer; the number of joint was 20,000,000 and the number of elements was 70,000,000.

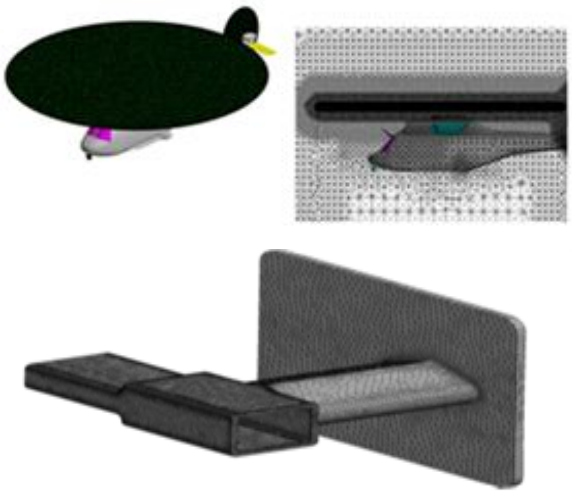


Fig.2. Computational configuration and meshFig.3. Computational configuration and mesh

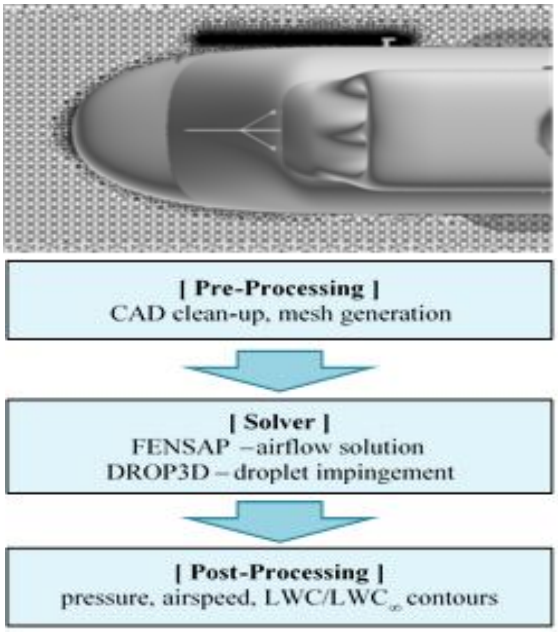


Fig.4. Computational configuration and mesh Fig.5. Computational configuration and mesh

3.2 Details of Analysis

As for the method of an analysis for the ice sensor positioning, through the distribution of ice water droplets within the flow field, the difference between the local LWC and air LWC_{∞} was compared according

to the change in the ice sensor position, and the position in which the difference in LWC became the minimum was chosen. As for the analysis of the flow field for this, based on the Navier-Stokes equation, k-e turbulence model was applied, and the trajectory of ice water droplets was calculated through analyses of drag, gravity and buoyancy. In other words, the continuity equation of Formula (1) and the momentum equation of Formula (2) were used, and here, α is the volume of ice water droplets;ρ is the density of ice water droplets; τpis the time of momentum reaction of particles; FP is power per unit mass; ūis the gas velocity factor; and u is droplet velocity vector.

$$\frac{\partial a\rho}{\partial t}+\nabla\cdot\left(a\rho\vec{u}\right)=0 \quad (1)$$

$$\frac{\partial a\rho\vec{u}}{\partial t}+\nabla\cdot\left(a\rho\vec{u}\vec{u}\right)=\frac{f\left(Re_r\right)}{\tau_p}\alpha\rho\left(\vec{u}_a-\vec{u}\right)+a\rho\vec{F}_p \quad (2)$$

In addition, the drag function of ice water droplets can be expressed like Formula (3).

$$f\left(Re_r\right)=1+0.15\left(Re_r\right)^{0.687}+\frac{0.0175}{1+\frac{4.25\times10^4}{Re_r^{1.16}}} \quad (3)$$

Where Rer isReynold's number according to the difference in velocity between gas and droplet, which is as follows:

$$Re_r=\frac{\left|\vec{u}_a-\vec{u}\right|d_p}{v_a} \quad (4)$$

IV. ANALYSIS RESULTS

4.1. Flow Field Analysis

With nine cases in Table 2 that shows icing conditions and flight conditions, the results of analyses of contours of the flow field of z-plane of the height of the ice sensor were shown in Fig. 6.

Table 2. Analysis conditions

Case	Flight Condition	A/S (m/s)	AOA (m/s)	AOS (deg)	OAT (°C)	MVD (μm)	LWC (g/m3)
1	Hover	0	-0.4	0	-1	20	0.2
2	Sideslip	3800	6.8	-9.2	-8.9	20	0.63
3	Climb	43	-12	0	-3	15	0.75
4	Climb	43	-12	0	-16.8	30	0.85
5	Level	64	16	0	-8.9	15	0.62
6	flight	64	16	0	-8.9	50	0.33
7	flight	70	0.7	0	-20.8	30	0.1
8	Descent	33	16	0	-8.9	15	0.62
9	Descent	33	16	0	-8.9	30	1

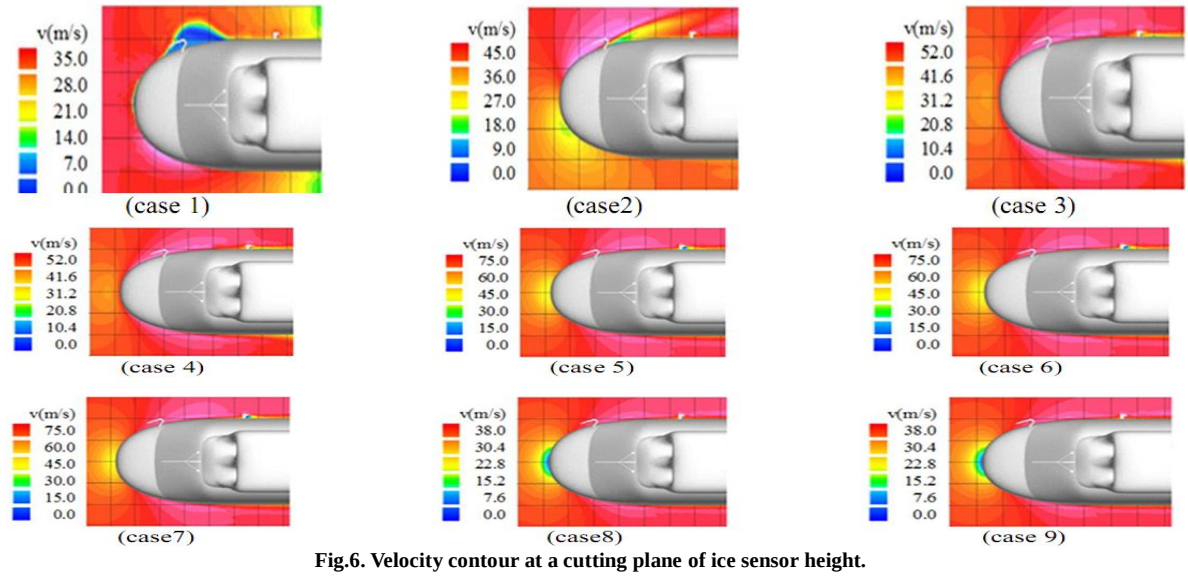


Fig.6. Velocity contour at a cutting plane of ice sensor height.

Case 1 is the result of an analysis of the flow field during a hovering flight, and it is found that the velocity of the flow field below the Pitot tube installed at the starting position of the windshield is somewhat low. This is because wake occurred because of the interference between downwash of the rotor and the Pitot tube during the hovering flight, and if the ice sensor was located more forward than the present position, it seems that there might be a bigger impact of wake during the hovering flight.

AOS flight condition of Case 2 shows a big difference in the air flow on the right and left of the helicopter. The air flow on the right of helicopter came in, so the air flow on the surface on the left became faster, and then stripping occurred at the position of the Pitot tube, so the velocity was reduced. In addition, it is found that there was no big difference in the flow field in the climbing flight of Cases 3 and 4, the level flight of Cases 5 through 7 and the descent flight of Cases 8 and 9. As the position of the stagnation point of the helicopter's nose part moves up and down because of the change in AOA of the air flow acting on the aircraft,

there was a change in the velocity in the section at the same height.

4.2 LWC Analysis

For each condition for analysis, the ratio of LWC and air LWC∞ (LWC/LWC$_\infty$) around the ice sensor was shown in Fig. 7. In the hovering flight of Case 1, downwash of the rotor runs into the Pitot tube, which produces wake, and consequently, LWC decreases at the back bottom of the Pitot tube, but it does not affect the ice sensor.

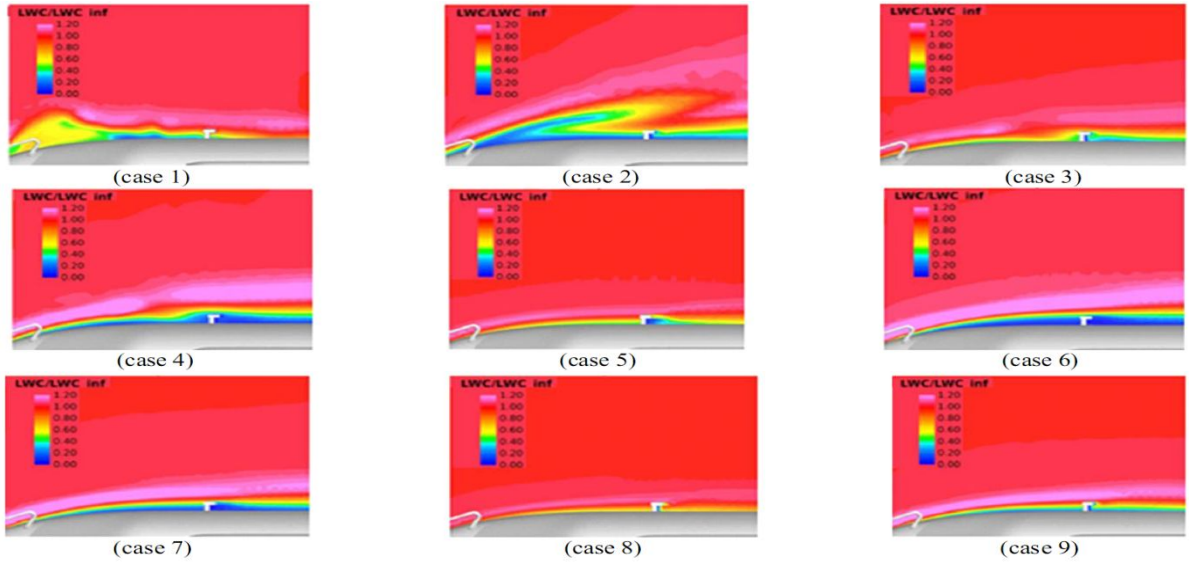


Fig.7. Velocity contour at a cutting plane of ice sensor height.

In AOS flight of Case 2, the surrounding LWC sank in the shadow zone because of the fuselage. The expected LWC at the height of the measuring part of the ice sensor is 60%, which is a big difference from the air LWC. However, during the AOS maneuver, the shadow zone cannot but be produced on the opposite side of the incidence angle of the air flow, and this maneuver is one in the transitional section, so it is judged that it is not necessary to change the position of the ice sensor for this.

In the climbing flight of Cases 3 and 4, the measuring part of the ice sensor sank in the shadow zone only in Case 4, which seems to be a difference by MVD. In the level flight of Cases 5 through 7, there were no ice water droplets on the measuring part of the ice sensor only in Case 6 with MVD of 50, while in Case 7 with MVD of 30 and fast velocity, too, the measuring part of the ice water droplets sank in the shadow zone. In addition, LWC changed by the difference in MVD in the descent flight of Cases 8 and 9, too.

4.3 Impacts of MVD, Velocity and AOS

In order to check the impacts of MVD and velocity, the results of an analysis of the flow field are shown in Fig. 8 As shown in the figure, if MVD increases, it is found that the measuring part of the ice sensor sinks in the shadow zone, and there is little impact of velocity. In addition, for hovering flight and AOS flight, the results of the flow field are shown in Fig. 9.

The surrounding flow filed is scattered by the impact of the Pitot tube during the hovering flight, which disturbs the ice sensor's accurate measurement, and during the AOS flight, the ice sensor may sink in the shadow zone.

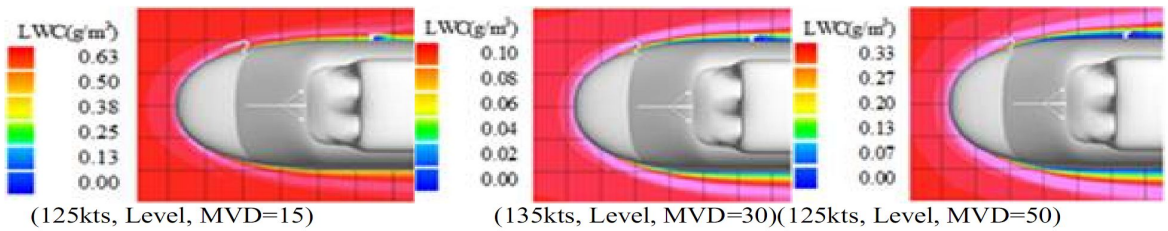


Fig.8. LWC contour by air speed and MVD.

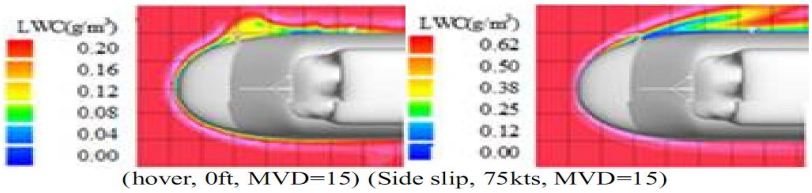


Fig.9. LWC Contour by Hover, air Speed and MVD.

V. DISCUSSION

Based on the measuring part of the ice sensor, the ratio of the local LWC to the air LWC∞ according to the height from the surface of the fuselage was illustrated in Fig. 10. It is found that, at the present position of the ice sensor (H=0mm), LWC/LWC$_\infty$ is between 0.2 and 1.4 according to flight conditions and icing conditions, and as the height increases, the local LWC become more similar to the air LWC$_\infty$(LWC/LWC$_\infty$≒1)

For all flight conditions and icing conditions, it is impossible to meet the measurement accuracy of LWC, considering the operational environment, and typically, it is necessary to consider that for level flight, the most common icing test flight condition. Thus, LWC ratios of Cases 5 through 7 considering various icing conditions for level flight were illustrated in Table 3. Since it shows the minimum error of 6 to 13% at a height of 90mm, it is judged that the results close to the air LWC∞ can be measured, if the ice sensor is installed so that it is projected about 90mm from the fuselage, which is higher than that in the present time.

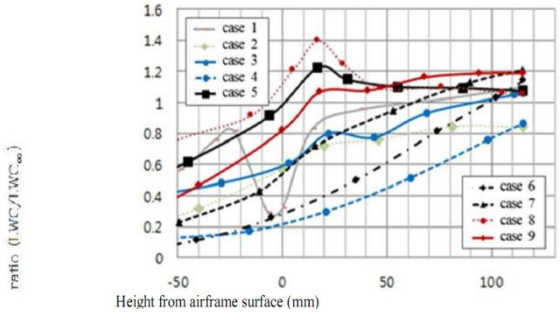


Fig.10. Relation between height from airframe surface and LWC ratio.

Table 3. LWC ratio by height with level flight

WC/LWC$_\infty$		
Case 5	Case 6	Case 7
1.12	0.62	0.94
1.1	0.7	0.99
1.09	0.78	1.04
1.09	0.86	1.09
1.08	0.94	1.13
1.08	1.02	1.16
1.08	1.1	1.2
1.08	1.18	1.23

CONCLUSIONS

The results of a 3-D data processing analysis conducted for the proper positioning of an ice sensor, considering a variety of factors such as environmental condition, flight condition and icing conditions are as follows:

• The helicopter sinks in the shadow zone if MVD exceeds 30;

• In the present ice sensor position, when various conditions are considered, LWC/LWC∞ is between 0.2 and 1.1; and

• When level flight condition is considered, if the height of the ice sensor is projected 90mm more from the fuselage, the icing measurement accuracy can be improved at an error range of 6 and 13%.

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