WIND TUNNEL TESTING OF PERFORMANCE DEGRADATION OF ICE CONTAMINATED AIRFOILS

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Abstract

An experimental investigation was conducted to study the aerodynamic effect of simulated supercooled large droplet ice accretion on a MS(1) 0313 aircraft airfoil by means of wind tunnel testing. The airfoil was equipped with an aileron with an axis of movement at 78 % of airfoil chord. Ice accretion was simulated by a strip of a quadrantal section with front edge perpendicular to the surface of the airfoil. Two strips of different dimensions were examined, of the height of 1.33 % of chord and 2.25 % of chord, respectively. Every strip was positioned at several positions on the upper surface of the airfoil, and its influence on the basic aerodynamic characteristics of the airfoil was evaluated, i. e. the lift, drag, moment and first of all the hinge moment of the aileron.

The ice accretion strip was positioned from 5 % to 45 % of chord, the deflections of aileron were up to 20 degrees down and 30 degrees up and the angle of attack was changed from 0 up to the angle of maximum positive and maximum negative lift coefficient. Wind tunnel tests were performed in the VZLÚ 3 m diameter low - speed wind tunnel at a Reynolds number of 2.10^6.

Simulation strips correspond with FAA recommendation, so data obtained from the wind tunnel measurements could indicate the development of aerodynamic characteristics which can be caused by the phenomenon of ice accretion under natural conditions, similar investigation [1]. Standard ice accretion requirements are described in FAR 25, Appendix C. It is clear that ice accretion can lead to large losses in lift, increases in drag and changes in the pitching moment. Especially behaviour of the lift and the hinge moment is of great interest as they are connected closely with the control of aircraft in complex conditions.

In addition, an experimental investigation of an ice contaminated airfoil wing glove was performed in the low speed wind tunnel at the Department of Aerospace Engineering, University of Glasgow as part of an ongoing reseach collaboration between both institutions. The aim of this programme was to optimise the wing glove geometry in order to use a UAV flying laboratory system currently under development in the Department [8].

Nomenclature

C_L		lift coefficient
C_D		drag coefficient
C_h		aileron-hinge moment coefficient
C_m		pitching moment
$C_{L\alpha}$		lift curve slope
$C_{h\alpha}$		aileron-hinge moment curve slope
$C_{m\alpha}$		pitching moment curve slope
c		model chord
α	(°)	angle of attack
η	(°)	eta - aileron deflection
Re		Reynolds number based on airfoil chord

Introduction

Aircraft can experience icing when, while flying at a level where the temperature is at or below freezing point, a cloud is encountered that contains super cooled water droplets. Ice accretion can have undesirable effects on aircraft performance, i.e. an increase of drag, a decrease of maximum lift and a decrease in the stall angle. The hinge moments of control surfaces could also be significantly affected by ice accretion. If the ice accretion occurs on the spanwise section of the wing where the aileron is located, it can alter the flow over the aileron and lead to changes in the lateral control and the associated hinge moment.

It is clear that ice accretion on aircraft surfaces can lead to deterioration of performance and aerodynamic characteristics. Therefore, the investigation of ice accretion by the experimental or computational methods [4] are important. If ice accretion is identified as a probable cause of loss of aircraft control, it can be attributed to the presence of supercooled large droplets in the atmosphere.

Supercooled large drops can form in several ways. One way is to form through the melting of snow as it falls through a warm layer of air. This can happen when a warm frontal layer penetrates through a cold layer of air, causing a temperature inversion with increasing altitude. Clouds above the warm layer produce snow which melts while falling through the warm layer and forms drizzle or rain drops. As the drops continue to fall, they enter the colder air layer again and are not likely to freeze again until they impact an object. If the lower cold air layer is at a sufficiently low temperature, the drops may freeze in the air to form ice pellets.

Wind tunnel model

The influence of ice accretion on a MS(1) 0313 aircraft airfoil with aileron was measured on a quadrangular model of a wing with circular end plates, the chord length 0.6 m.

Two types of simulated ice accretion by a strip of quadrantal section were examined, of height 1.33 % and 2.25 % of chord respectively, for different protuberance height [2], [3]. Either strip was positioned on the upper surface of the airfoil at locations from 5% to 45 % of chord.

Experimental method

The tests were performed in the 3 m diameter low speed wind tunnel at VZLU, Aeronautical Research and Test Institute in Prague (Czech Republic). The wind tunnel used was an atmospheric open - section, closed return.

All tests were performed at the Reynolds number 2.10^6. The deflections of aileron were up to 20 degrees down and 30 degrees up and the angle of attack was changed from 0 up to the angle of maximum positive and maximum negative lift coefficient.

The aerodynamic coefficients measured such as lift coefficient, drag coefficient and pitching moment coefficient were calculated by standard methods with conventional definitions. The hinge moment measured about the aileron hinge line was obtained by a strain gauge balance built in the aileron.

The following configurations were measured:

- Clean airfoil (airfoil with aileron without ice accretion). This configuration was provided as a reference configuration.
- Airfoil with aileron and lower ice accretion positioned at 5 %, 25 %, 35 % and 45 % of chord.
- Airfoil with aileron and higher ice accretion positioned at 5 %, 25 % and 45 % of chord.
- Airfoil with aileron without ice accretion, with aileron gap sealed.
- Airfoil with aileron, smaller ice accretion, with aileron gap sealed.

Results

Lift curve

All of the simulated ice accretions reduced lift curve slopes in the linear regions when compared with the clean case and dramatically reduced the maximum lift coefficient. The lift curve in the negative angle of attack was almost independent on the ice accretion presence and its position. In the region of a positive angle of attack the influence of ice accretion and its position were strongly apparent.

The ice accretion exhibited a large break in the lift curve slope between 2 ° and 5 ° angle of attack. It was likely due to a partial flow separation. However, the simulated ice accretion moving on the leading edge increased the lift curve slope and reduced maximum lift coefficient. It is shown in Fig. 2 that the worst ice accretion location for maximum lift coefficient degradation was at x/c = 5 %. Fig. 3 shows the drag polars with simulated ice accretions at the different locations.

Drag
The presence of ice accretion shown in Fig. 3 significantly increases in drag independently of ice accretion position. The flow separation in the higher lift coefficients by moving the ice accretion on the leading edge was exhibited by different lift curve slope of drag polar.

Moment
The pitching moment exhibited in irregular moment curve and reducing a range of values. The moment curves are shown in Fig. 4.

Hinge moment
Probably one of the dangerous effects of ice accretion on aircraft is the change in the pilot's ability to control the aircraft. The presence of ice accretion in Fig. 5 significantly affected the hinge moment. The range of hinge moment coefficient values were reduced especially in positive angle of attack or positive lift coefficient, respectively. It is apparent that the influence of ice accretion is increased when ice accretion moves on the leading edge.

Aerodynamic derivatives $C_{L\delta}$,$C_{h\delta}$
The ice accretion significantly affected the aerodynamic derivatives $C_{L\delta}$,$C_{h\delta}$ defining a basic effect of aileron. The appropriate diagrams are in Fig. 6-9.

The influence of ice accretion was more exhibited in the region of positive angle of attack where the influence of the aileron was reduced by moving ice accretion on the leading edge. The $C_{L\delta}$ value was also reduced for ice accretion at 25 % and 45 % of chord where the normal devices for ice accretion elimination are not effective. In the region of negative angle of attack, $C_{L\delta}$ value was increased moving ice accretion at the trailing edge.

Aileron gap reduction

Aileron gap reduction between the fixed part of the airfoil and the aileron from 0.55 % to 0.2 % was slightly exhibited.

The lift coefficient was slightly increased for zero and positive aileron deflections, especially at a positive angle of attack. The critical angle of attack and maximum lift coefficient were washily reduced.

The drag coefficient was reduced with positive lift coefficients and for higher lift coefficients reached more significant values, more than 10 %.

The influence on the moment curve was not significant. The bigger differences were observed on the hinge moment, with ice accretion positioned at 35 % of chord for negative aileron deflections near zero angle of attack.

Conclusions

An experimental investigation was conducted to study the aerodynamic effect of simulated ice accretion corresponding with FAA recommendations. The following conclusions can be drawn.

- Ice accretion strongly affects the lift and drag of an airfoil. The maximum lift coefficient is reduced and drag is increased several times.
- The moment is not significantly changed.
- The efficiency of aileron deflections is deteriorated and $C_{L\delta}$ falls.
- The influence of ice accretion is increased by movement on the leading edge of the airfoil.
- Hinge moment is strongly influenced in certain area of angle of attack.
- The bigger ice accretion slightly exhibits in bigger influence.
- The aileron gap reduction was not significantly pronouced.

The presence and location of ice accretion significantly affected all the aerodynamic characteristics of an airfoil with aileron. Special attention was devoted to the characteristics affecting the control surfaces such as lift and hinge moment. All the diagrams, in this paper, show the lower ice accretion.

Acknowledgements

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References

[1] Lee S, Bragg M, B. Experimental investigation of simulated large-droplet ice shapes on airfoil aerodynamics. Journal of Aircraft, Vol. 36, No. 5, 1999.

[2] Bragg M, B. Aerodynamics of supercooled large droplet ice accretions and the effect on aircraft control. www.uiuc.edu, 1996.

[3] Bragg M, B. Aircraft aerodynamic effect due to large droplet ice accretions. www.uiuc.edu,1996.

[4] Dunn T, A, Loth E, Bragg M, B. Computational investigation of simulated large droplet ice shapes on airfoil aerodynamics. Journal of Aircraft, Vol. 36, No. 5, 1999.

[5] Cooper W, A, Sand W, R, Politovich M, K, Veal D, L. Effect of icing on performance of a research airplain. Journal of Aircraft, Vol. 21, No. 9, 1984.

[6] Calay R, K, Holdu A, E, Mayman P. Experimental simulation of runback ice. Journal of Aircraft, Vol. 34, No. 2, 1997.

[7] Reehorst A, Chung J, Potapczuk M, Choo Y. Study of Icing Effects on Performance and Controllability of on Accident Aircraft. Journal of Aircraft, Vol. 37, No. 2, 2000.

[8] Darida M. Design Approach with Wind Tunnel Test Data on RPV Laboratory for On Flight Aerofoil Testing. MSc Theses, University of Glasgow, 1998.

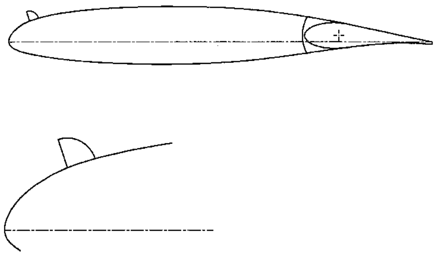

Fig. 1 Shape of MS(1)-0313 with aileron and ice accretion positioned at 5 % of chord

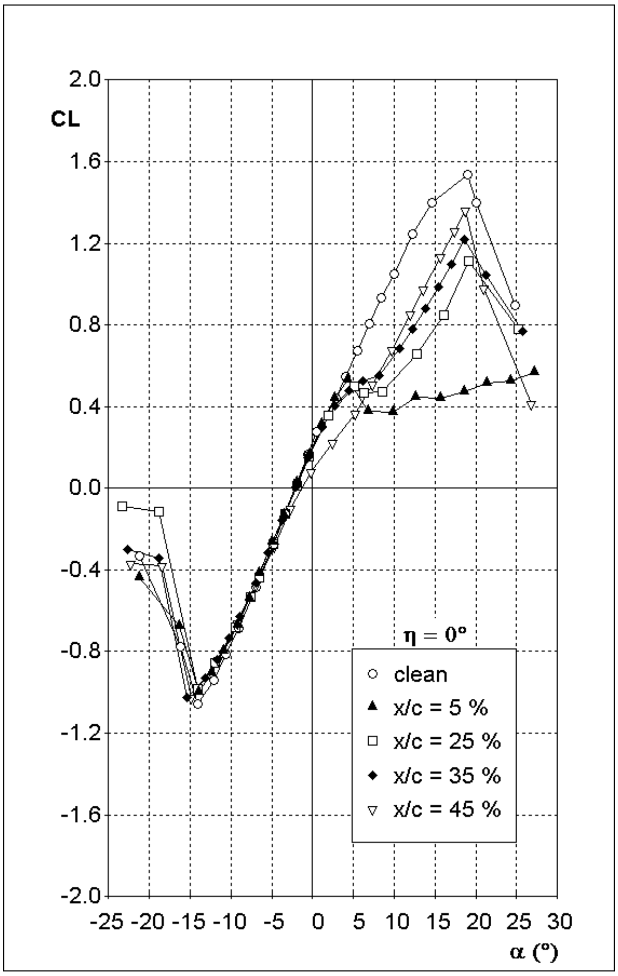

Fig. 2 The influence of ice accretion on lift curves at different locations.

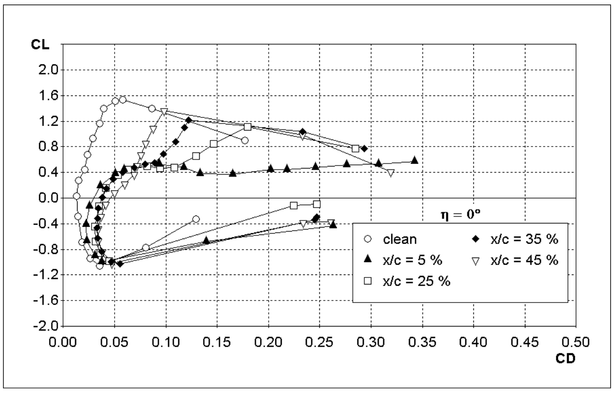

Fig. 3 The influence of ice accretion on drag polar at different locations

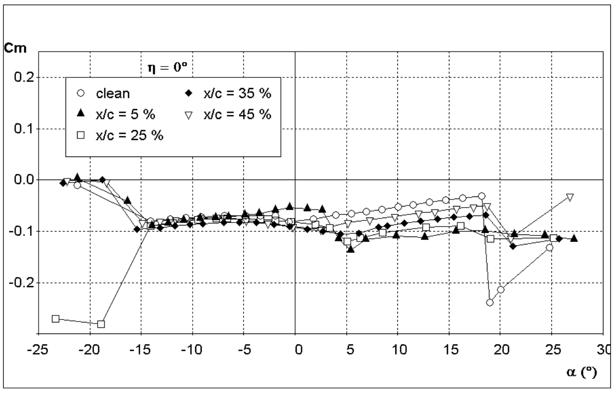

Fig. 4 The influence of ice accretion on pitching moment at different locations

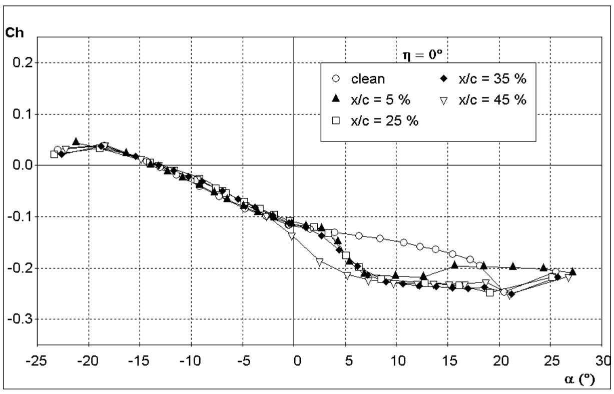

Fig. 5 The influence of ice accretion on hinge moment at different locations

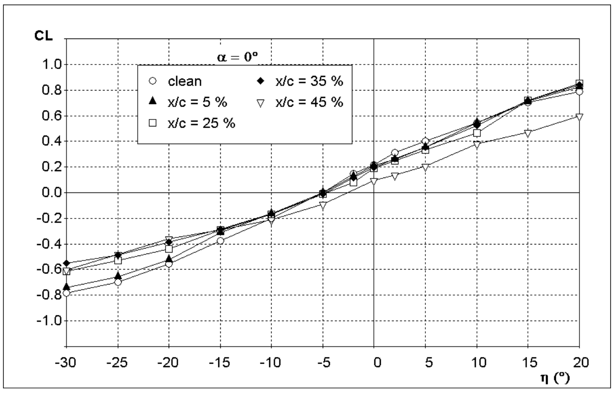

Fig. 6 The influence of ice accretion on C_L against η at different locations

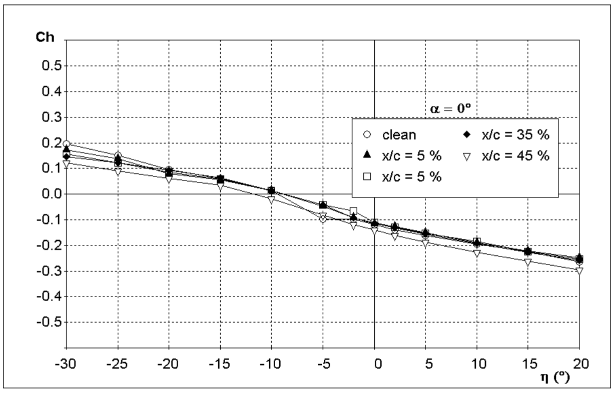

Fig. 7 The influence of ice accretion on C_h against η at different locations for α = 0°

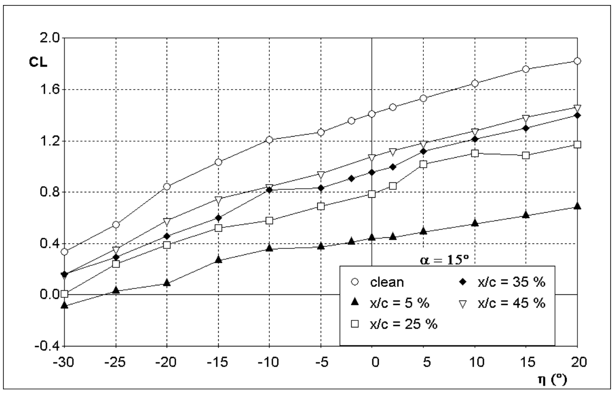

Fig. 8 The influence of ice accretion on C_L against η at different locations for α = 15°

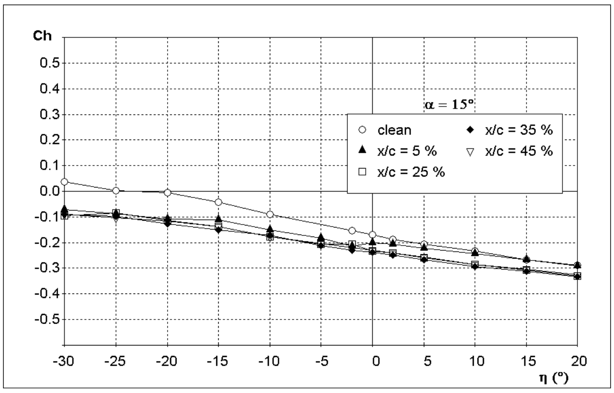

Fig. 9 The influence of ice accretion on C_h against η at different locations for α = 15°

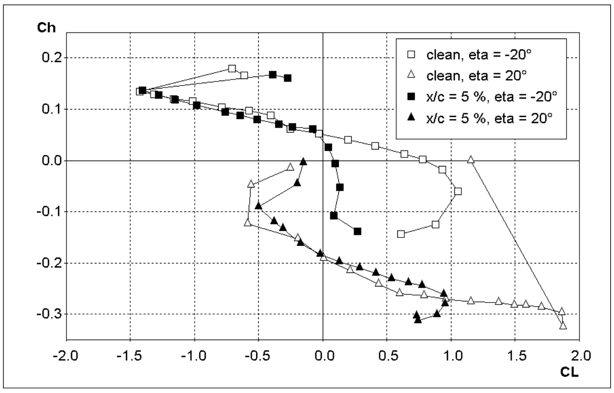

Fig. 10 Comparison of the influence of ice accretion on hinge moment for different aileron deflections

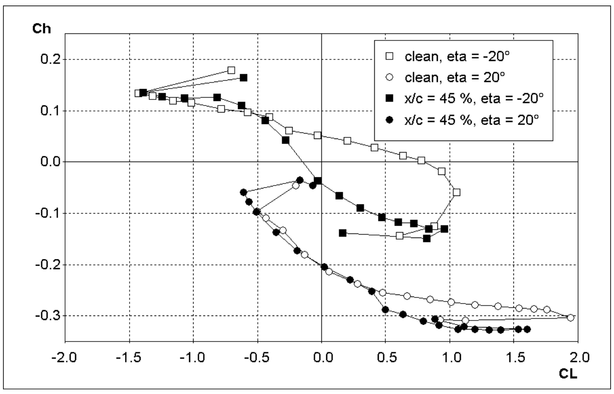

Fig. 11 Comparison of the influence of ice accretion on hinge moment for different aileron deflections

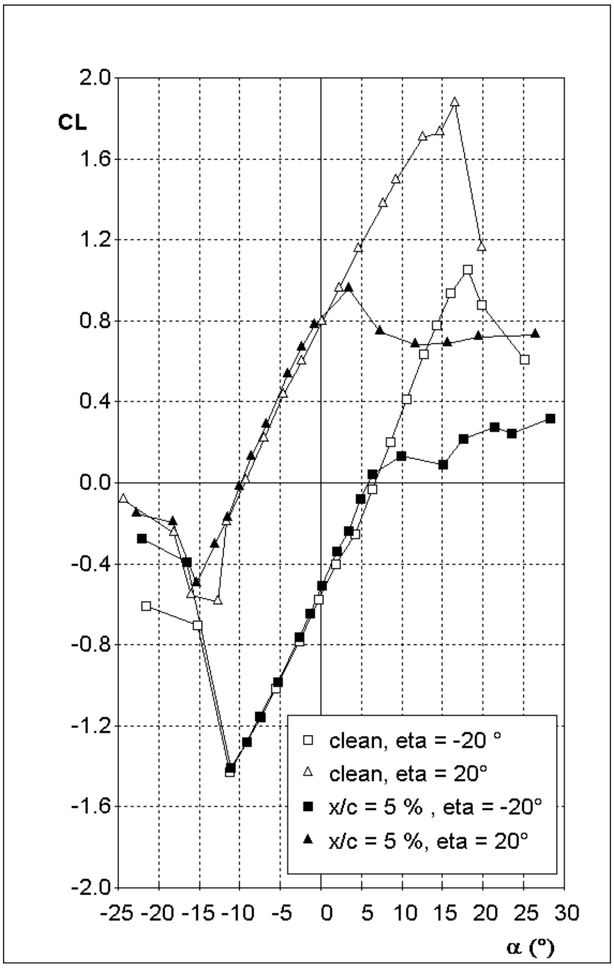

Fig. 12 Comparison of the influence of ice accretion on lift curve for different aileron deflections

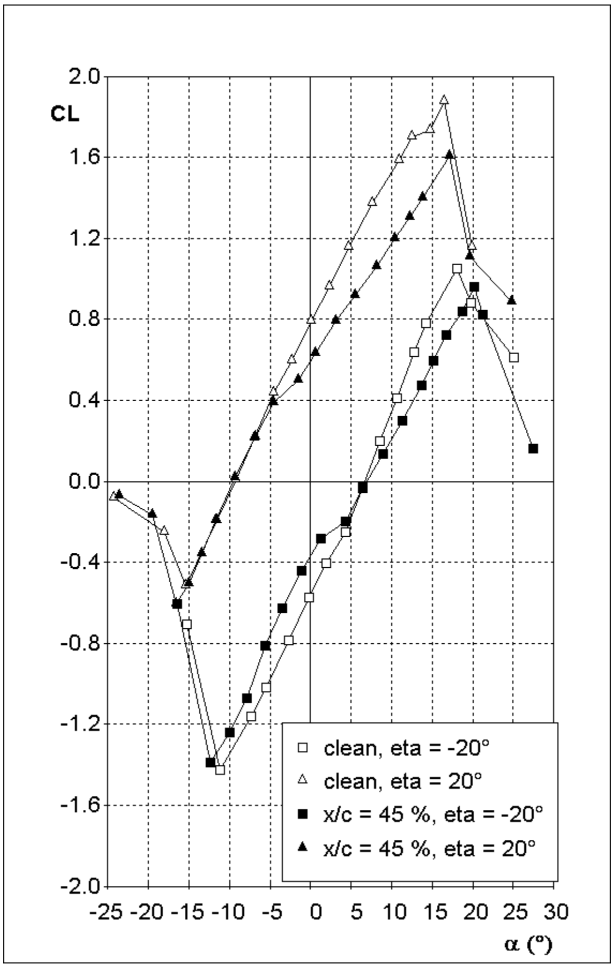

Fig. 13 Comparison of the influence of ice accretion on lift curve for different aileron deflections