THE EFFECT OF ICE-ACCRETION ON THE LATERAL CONTROLLABILITY

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Abstract

The project is aimed to provide data to evaluate the influence of the ice accretion on aircraft flight characteristics and therefore to ensure considerable safety in the course of flight-testing. Indeed it will be possible to use these results in the course of the certification procedure.

The task definition was to locate the simulator of the ice-accretion behind the active surface of the de-icing system and perform a calculation of the aerodynamic forces and moments acting on the whole airfoil section and on the aileron.

The first step was to find the position of ice-accretion for varied droplet diameters. The next step was to analyze the aerodynamic characteristic of the airfoil with imitation of the ice-accretion on the upper surface of the airfoil using commercial software FLUENT. The paper is focused on this part of the solution.

An influence of the ice accretion on the aileron hinge moment in reference to the aeroplane ability to exit safely the icing conditions is reviewed in the conclusion.

1 Introduction

Based on the FAA Issue Paper and discussion between FAA and LET a task to solve aerodynamic characteristic of the aeroplane in the ‘Supercooled Large Droplet Conditions’ was defined.

LET and Institute of Aerospace Engineering, Brno University of Technology carried out an estimation of the influence of the asymmetric ice shapes located forward of only one aileron on the upper surface of the wing to increase the safety during the certification flight tests.

2 Supercooled Large Droplets (SLD)

The ice-accretion considered in this paper is caused by the icing conditions called “Supercooled Large Droplets”. The droplet diameters ranging from 50 to 400 microns in these conditions and medium volumetric diameter should not be less than 170 microns. A liquid water content is not less than 0.6 grams per cubic meter, nor greater than 0.9 grams per cubic meter. Temperatures are near freezing.

Factors which affect an ice formation:

- Temperature
- Median volume diameter – MVD
- Liquid water content – LWC
- Size and shape of the component of the aircraft
- Velocity
- Angle of attack
- Exposure time

3 Purposes of SLD condition evaluation

Main purpose of SLD condition evaluation is the size of droplets. The size is considerably bigger than the maximum size specified in FAR 25, appendix C – Fig.1.

Why turboprop aeroplanes? There is a study showing that turboprop aeroplanes is the most affected category of the airliners in the regular operation in encountering icing conditions.

Turboprops: exposure time – 0.006 hours per Flt.

Jets: exposure time – 0.002 hours per Flt.

4 Calculation

An analysed wing section is modified MS-0313. It is located at the inboard edge of the aileron.

The locations of the ice-accretion were calculated by a third party, using the RAMPANT software for a tracking of particle trajectories.

The agreement between the FAA and LET prescribed the shape and dimensions of the ice-accretion imitation. This is a 1-inch radii quarter circle, placed by the sharp vertical face toward the incoming air stream on the upper surface of the airfoil (see Fig 2.).

We took the resulting positions of ice-accretion and performed calculation to determine which location is the most critical. The criterion taken for this evaluation was the highest change in the hinge moment of the aileron with and without ice ridge. Figure 3. shows that the most critical position according to this criterion is at 30% of the chord.

With the ice imitation placed in the most critical position we performed calculation with several different deflections of the aileron. We also performed a calculation of the clean airfoil for a comparison. As a result, there is Fig. 4. showing the aileron hinge moment with and without the ice imitation in a correlation with the aileron deflection. For the same conditions a change of the airfoil lift coefficient was analysed because it affects a load distribution along wing span and causes rolling moment (Fig. 5).

5 Conclusions

5.1 Equilibrium deflection

The ice shape placed asymmetrically on one wing along the aileron span causes rolling moment, which must be balanced by the aileron deflection for straight flight. The Weissinger method was used for recalculation of the 2D RAMPANT results to establish (3D) rolling moments and derivatives of the wing needed for a following analysis.

$$(m_x)_L = (m_x)_{LW} \cdot \frac{(\Delta c_L)}{2 \cdot c_L^{\alpha}} \qquad (1),$$

where:

$(m_x)_L$ – rolling moment coefficient caused by ice-accretion ridge

$(m_x)_{LW} = 0.338$ – unit rolling moment coefficient caused by ice-accretion ridge calculated using Weissinger method

Δc_L – lift coefficient increment on the airfoil with and without ice-accretion

$c_L^{\alpha} = 6.664$ – lift curve slope

from moment equilibrium

$$(m_x)_L = -m_x^{\delta k\varnothing} \cdot \bar{\delta}_{k\varnothing} \quad \Rightarrow \quad \bar{\delta}_{k\varnothing} = \frac{(m_x)_L}{-m_x^{\delta k\varnothing}} \qquad (2)$$

where :

$m_x^{\delta k ř} = -0.133$ – derivative of rolling moment coefficient due to aileron deflection at 0° AOA and cruise configuration

$\bar{\delta}_{k\varnothing}$ – reference airleon deflection

The resulting equilibrium deflection is $\boxed{\bar{\delta}_{k\varnothing} = \mathbf{1.447°}}$. The deflections of the right and left aileron are almost the same in range of small deflections.

5.2 Angular velocities

Manoeuvreability changes can also be an indicator of ice-accretion influence.

We started with basic equation for lateral manoeuvreability that considers the influence of ice-accretion (all the moments causing roll to the right side are positive).

$$(m_x)_L + m_x^{\delta_{k\o}} \cdot \delta_{k\o} + m_x^{\bar{\omega}_x} \cdot \bar{\omega}_x = 0$$

$$\bar{\omega}_x = -\frac{(m_x)_L + m_x^{\delta_{k\o}} \cdot \delta_{k\o}}{m_x^{\bar{\omega}_x}} \qquad (3),$$

$$\omega_x = \frac{2 \cdot v}{l} \cdot \bar{\omega}_x$$

where :

$m_x^{\bar{\omega}x}$ – derivative of rolling moment coefficient due to angular velocity in roll

$\bar{\omega}_x$ – dimensionless angular velocity in roll

ω_x – angular velocity in roll

l – wing span

First we performed calculation of angular velocity in roll caused by ice-accretion placed asymmetrically on the right wing. There is no deflection of aileron to prevent the roll.

Case 1. - $\delta_{k\o}$ = 0°; $m_x^{\delta k\check{r}}$ = - 0.133 (flaps 0°);
$m_x^{\bar{\omega}x}$ = - 0,512 (Weissinger method);
$(m_x)_L$ = 0.0033577 (ailerons 0°);
v = 275 km/h = 76.4 m/s (speed);
l = 25.6 m

Applying the values listed above to the equation (3) we obtain:

$\bar{\omega}_x = 0.00656$

$\omega_x = 0.03915\, {}^{rad}/_{s} = 2{,}243\, {}^{\circ}/_{s}$

Next two cases deal with manoeuvreability during the landing manoeuvre, when max. deflections of ailerons can be used. Speed is 180.5 km/h and flaps are fully deflected (26°).

Case 2. - $\delta_{k\o}$ = 22.5° = 0.39267 rad;
$m_x^{\delta k\check{r}}$ = - 0.142 (flaps 26°);
$\delta_{k\check{r}P}$ = +15°; $\delta_{k\check{r}L}$ = -30°;
$(m_x)_L$ = 0.0078616 (right aileron +15°);
$m_x^{\bar{\omega}x}$ = - 0.512 (Weissinger method);
v = 180.5 km/h = 50.14 m/s (final approach speed); l = 26.5 m

Applying the values listed above to the equation (3) we obtain:

$\bar{\omega}_x = -0.0936$

$\omega_x = -0.366\, {}^{rad}/_{s} = -20{,}997\, {}^{\circ}/_{s}$

Case 3. - $\delta_{k\o}$ = - 22.5° = - 0.39267 rad;
$m_x^{\delta k\check{r}}$ = - 0.142 (flaps 26°);
$\delta_{k\check{r}P}$ = -30°; $\delta_{k\check{r}L}$ = +15°;
$(m_x)_L$ = - 0.0070882 (right aileron -30°);
$m_x^{\bar{\omega}x}$ = - 0.512 (Weissinger method);
v = 180.5 km/h = 50.14 m/s (final approach speed); l = 26.5 m

Applying the values listed above to the equation (3) we obtain:

$\bar{\omega}_x = -0.0951$

$\omega_x = -0.372\, {}^{rad}/_{s} = -21{,}336\, {}^{\circ}/_{s}$

The last case can be compared with two previous cases without ice-accretion. This case is the same for right and left side roll.

Case 4. - $\delta_{k\o}$ = ±22.5° = ±0.39267 rad;
$m_x^{\delta k\check{r}}$ = - 0.142 (flaps 26°);
$m_x^{\bar{\omega}x}$ = - 0.512 (Weissinger method);
v = 180.5 km/h = 50.14 m/s (final approach speed); l = 26.5 m

Applying the values listed above to the equation (3) we obtain:

$\bar{\omega}_x = \pm 0.109$

$\omega_x = \pm 0.427\, {}^{rad}/_{s} = \pm 24{,}444\, {}^{\circ}/_{s}$

This calculation is showing that the angular velocity in roll to the left side will be 14,1% lower with ice-accretion than without it. And the roll velocity to the right side will be 12,7% lower with ice-accretion than without it.

6 Summary

Finally, even though there is not a possibility to evaluate all the consequences of the ice-accretion presence on the upper surface of the L-610G wing, the results indicate that the aircraft is less manoeuvrable but still safely controllable. Therefore it will be able to leave SLD conditions.

The required aileron deflection for an elimination of rolling moment caused by ice-accretion is very small. Therefore pilot will not have any problem with roll control in straight flight.

In figure 6 is an example of the flow field above the airfoil section with the ice accretion and negative aileron deflection. All calculations were performed for a small angle of attack. This parameter could have an important influence on the analyse characteristics. Similar analysis should be carried out for higher angles of attack.

References

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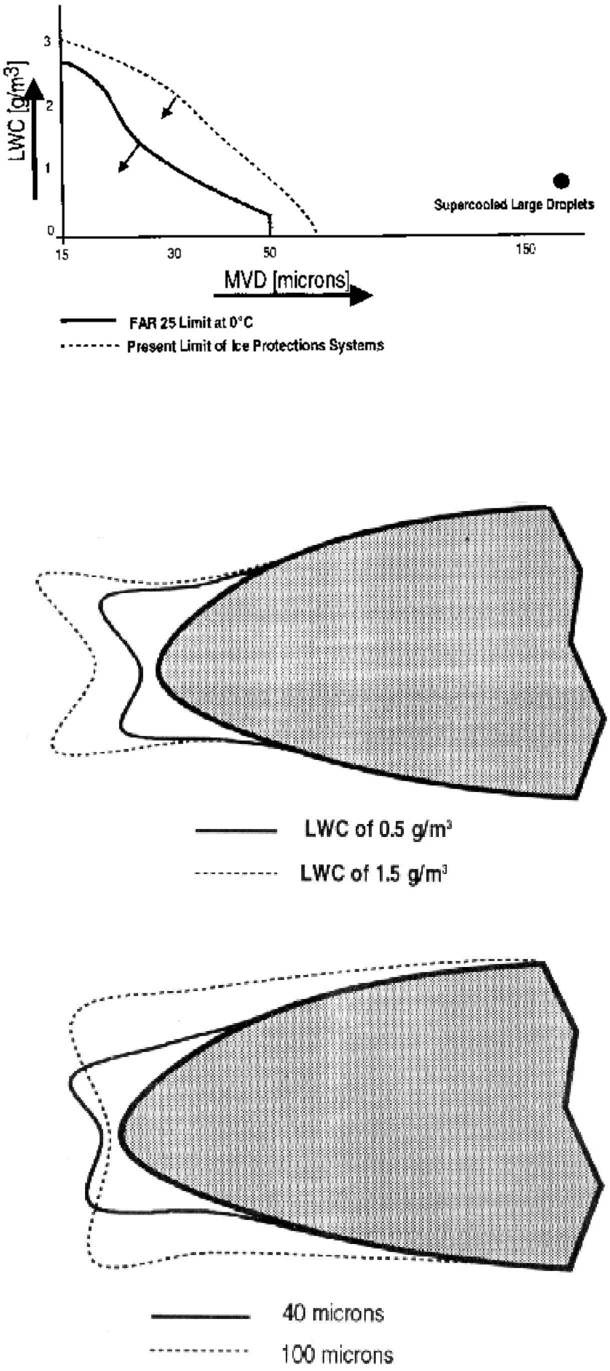

Fig. 1. Exceedence of condition in FAR 25 – first picture and LWC and MVD influence on ice-accretion position – next two pictures.

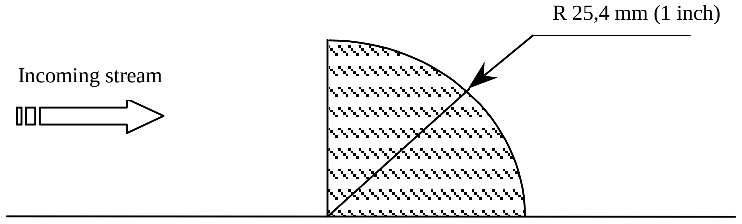

Fig. 2. Shape of ice-accretion imitation prescribed by FAA

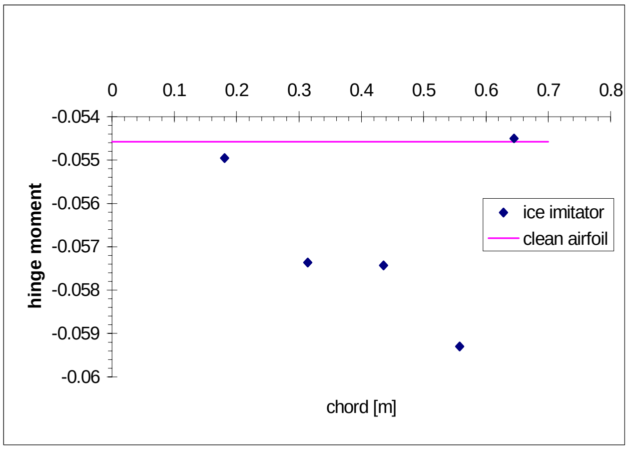

Fig. 3. Most critical position according to aileron hinge moment

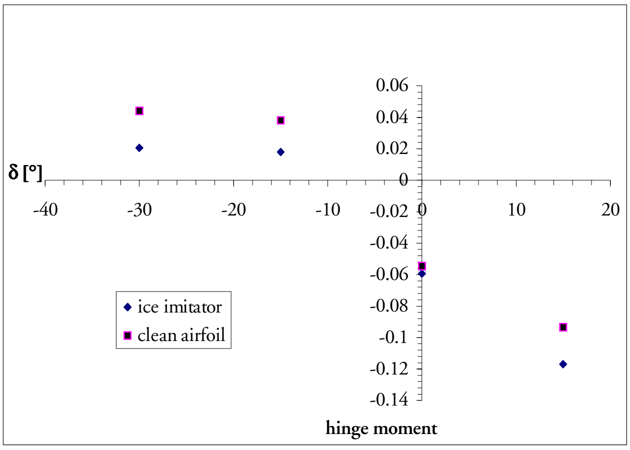

Fig. 4. Change of hinge moments on the aileron with and without ice imitation according the aileron deflection

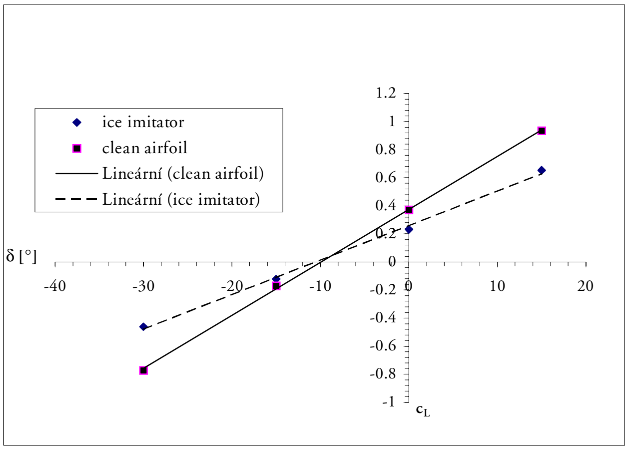

Fig. 5. Difference in lift coefficients resulting in roll behaviour change

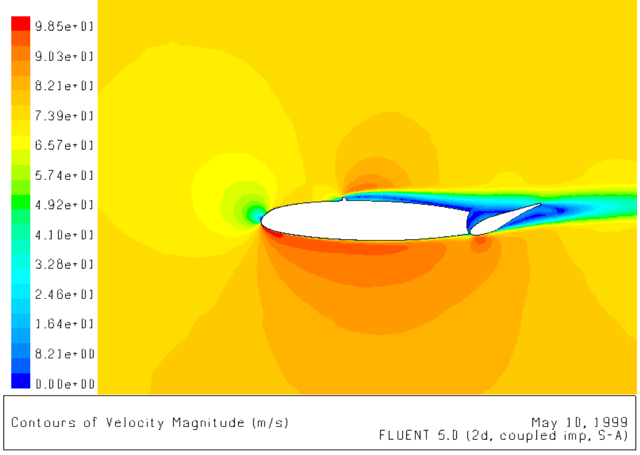

Fig. 6. The flow field change above the upper surface of the airfoil due to negative aileron deflection