WIND TUNNEL AND COMPUTIONAL INVESTIGATION OF SIMULATED CONTAMINATION ON AIRFOIL

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Abstract

A study of aerodynamic characteristics of an advanced low-speed airfoil section with Fowler flap was made. Consequences of ice contamination of the airfoil were examined. The studied cases were computed by the flow solver and measured in the low-speed wind tunnel. Results from different approach were compared.

1 Introduction

The adverse influence of the ice accretions on the performance of aircraft is known and studied for the decades, many fundamental studies were published, for example [1],[2]. But nevertheless many items remains to study as the icing can be extremely dangerous. Rim ice accretion caused by the supercooled large droplets, one of the icing types, is relatively recently discovered phenomenon. The influence of this type of the icing on an advanced currently used airfoil with Fowler flap was studied both experimentally and by a computational method. The intention was not only to study aerodynamic influences but also to evaluate possibilities of a relatively simple time-saving computational method. The paper reassumes already published studies [3],[4],[5].

2 Nomenclature

c_D	drag coefficient
c_L	lift coefficient
c_m	moment coefficient
c_p	pressure coefficient
α	angle of attack
δ	flap deflection

3 Airfoil section

The NASA MS(1)-0317 airfoil section [7],[8] was used as a representative of advanced airfoils currently used for the low-speed general aviation aircraft. The airfoil was equipped with a Fowler flap of chord of 30 percent of the airfoil chord. The deflected positions of the flap had been optimized for the take-off (20 degrees) and the landing (35 degrees).

4 Model for the wind tunnel testing

A model in the form of a rectangular wing (1200 mm span, 600 mm chord) with rectangular end plates was used. There were pressure taps on the model, on the main airfoil (including in the cove) and on the flap.

5 Wind tunnel

The tests were performed in the VZLU 3mLSWT low-speed wind tunnel. The test section is of 3 meter diameter, maximum velocity is 70 meters per second.

The pressures were measured by a pressure block, the integral forces were measured by means of mechanical balance.

6 Ice accretion

The ice accretion was of a shape recommended by FAA. The icing creates a rim formed on the upper side of the airfoil, its cross-section was of quadrantal shape with the leading edge perpendicular to the airfoil upper surface. This shape is considered as typical for the accretions caused by the supercooled large droplets. The height of the accretion was 2.25 per cent of the airfoil chord.

The accretion was positioned at 5 or 15 or 25 percent of the chord from the leading edge. The first position represented the situation without operating de-icing device, the other two positions represented the accretion created more downstream that is the typical case for the supercooled large droplets conditions even with de-icing device operating.

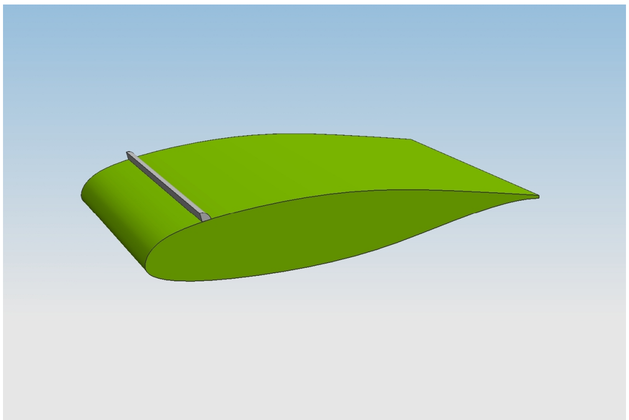

Fig. 1 Airfoil with ice accretion

7 Wind Tunnel Results

7.1 Lift

The lift potential of the airfoil was completely destroyed by the studied accretion model as was seen already from the pressure distributions. The influence was nearly identical independently on the ice accretion position, certain differences were observed according to the flap deflection.

More in detail, it is visible that the results for the position of 25 percent were very slightly less influenced than for the accretions nearer to the leading edge. But the reduction of the maximum lift coefficient was dramatic in all tested configurations, even in the critical case of the landing configuration, where the maximum magnitude diminished to the order of the maximum of the cruise configuration.

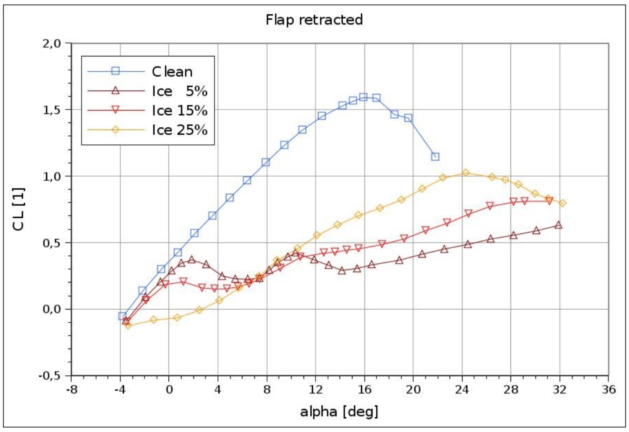

Fig. 2a Lift curves

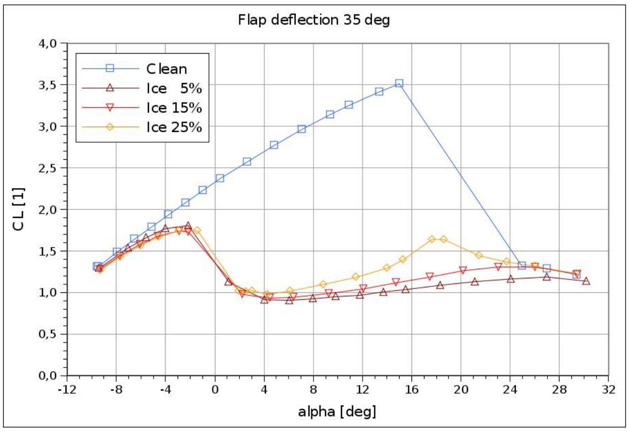

Fig. 2b Lift curves

7.2 Drag

As the deformations of the pressure distributions indicated, the loss of the lift was accompanied by the significant increase of the drag at the constant angle of attack (Fig. 3). The polars show that the lost of the lift was extreme with the accretion at the same drag as without the accretion. For example, the lift coefficient decreased from 1.59 to 0.34 at least (21 percent) at the drag coefficient of 0.068 for the cruise configuration, or from 3.32 to 1.81 (55 percent) at the drag coefficient of 0.188 for the landing configuration.

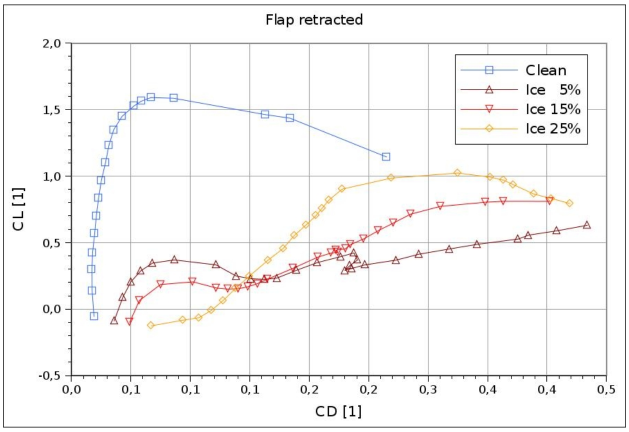

Fig. 3 Polar curves

7.3 Lift-to-drag ratio

The development of the lift-to-drag ratio (Fig. 4) for the airfoils with retracted flap and with flap deployed at 35 degrees illustrates the extent of the loss of the aerodynamic performance. It is visible that the only noteworthy remnant of the performance only was evaluated at the flap deflection of 35 degrees, but even in this case the performance was damaged to the high extent as the lift-to-drag ratio decreased to 50 percent approximately.

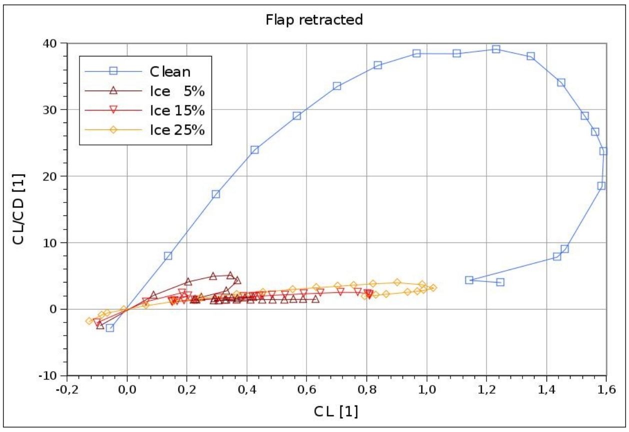

Fig. 4 Lift-to-drag curves

7.4 Moment

The most significant change occurred for the retracted flap, where the moment coefficient decreased approximately by -0.025. No important change was observed for the flap deflection of 20 degrees. It is interesting that the change was positive by (up to) 0.05 for the deflection of 35 degrees.

The influence on the shift of the aerodynamic center was not systematic but it seems that the shift was of the order of few percent.

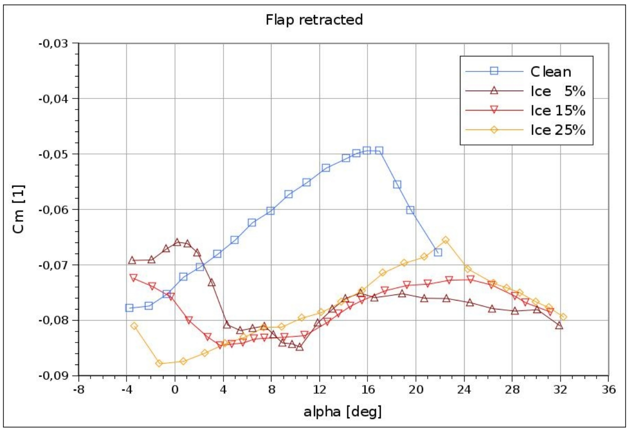

Fig. 5 Moment curves

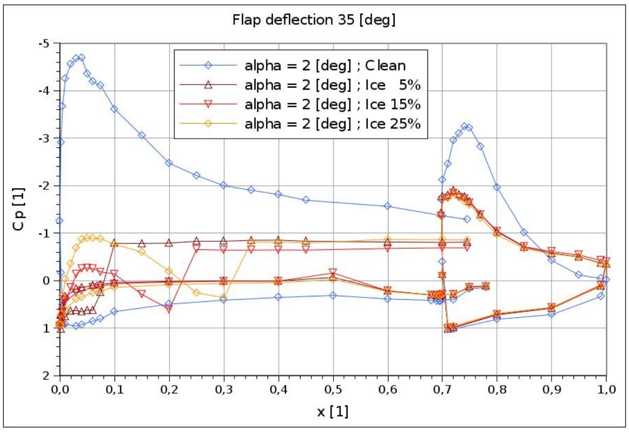

Fig. 6 Pressure distributions

8 Computation

8.1 Mesh

The mesh was generated with the in-house code hypgrid2d, which generates structured 2D mesh. The O-grid type mesh was used in our case. The number of cells was from 50 000 to 100 000, depending on the specific computational case.

8.2 Flow solver

We used the EDGE code, developed in FOI, Sweden to solve the N-S equations. EDGE is a parallelized flow solver for 2D/3D viscous/inviscid flow.

8.3 Results

The results showed very good correspondence for both cases, with or without ice accretion. For the cases with ice accretion, the computation detected the behaviour of the flow around the ice ridge, which can explain the measured results.

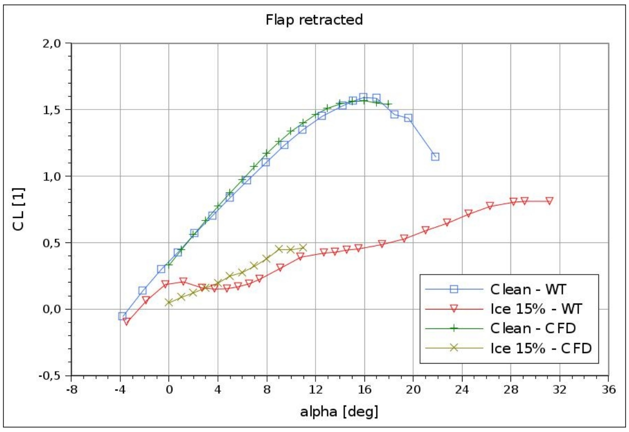

Fig. 8a Lift curves

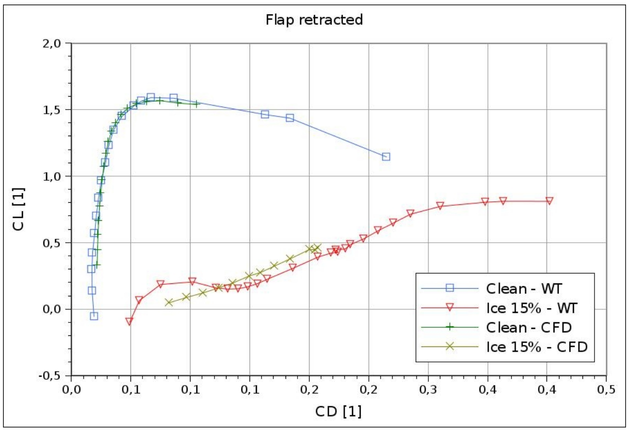

Fig. 8b Polar curves

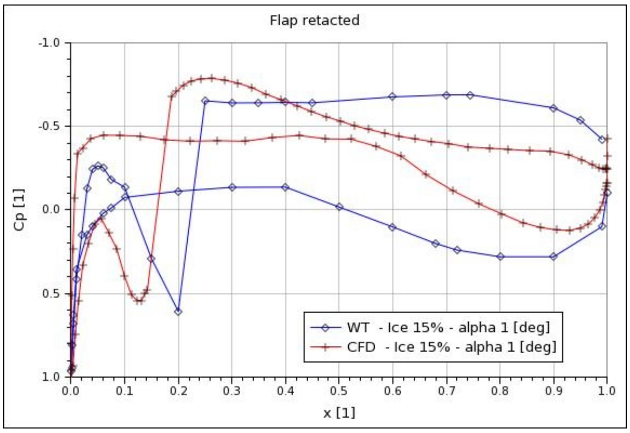

Fig. 8c Pressure distributions

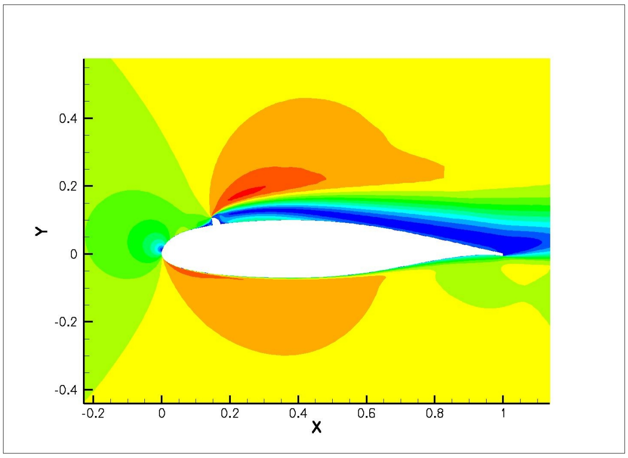

Fig. 9 Mach number contours

8 Conclusions

The extreme danger of the icing conditions with the supercooled large droplets was once more confirmed, this time for an advanced low-speed general aviation airfoil. The ice rims created outside the area of effect of de-icing device have destroying consequences on the pressure distribution and thus on global aerodynamic performance of the airfoil. The intensity of the consequences was extremely pronounced regardless of the flap deflection.

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