EXPERIMENTAL INVESTIGATION OF SIMULATED ICE ACCRETION ON TURBOPROP AIRCRAFT

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Keywords: *aerodynamics, flight mechanics, ice accretion, icing*

Abstract

An experimental investigation was conducted to study the aerodynamic effect of simulated ice accretion on a wing and horizontal tailplane of an aircraft by means of wind tunnel testing. The aircraft was of a two-engine turboprop commuter type. Ice accretion was simulated by strips of different shapes positioned either ahead of the right aileron or ahead of the elevator. The strips of two cross sections were examined, of a V shape section simulating a conventional leading-edge ice accretion and of a quadrantal section with front edge perpendicular to the upper surface of the airfoil simulating an ice accretion caused by supercooled large droplets. Its influence on the basic aerodynamic characteristics of the aircraft was evaluated, i. e. the lift, drag, side force and moments.

The V shape ice accretion strip was positioned at the leading edge of the wing or the stabiliser, the quadrantal strip from 5 % to 45 % of chord. The deflections of aileron were up to 30 degrees and the angle of attack was changed from 0 up to the angle of maximum positive lift coefficient. The deflections of elevator were up to 10 degrees down and 27 degrees up and the angle of attack was changed from 0 up to the angle of maximum positive lift coefficient. Wind tunnel tests were performed in the VZLÚ 3 m diameter low - speed wind tunnel.

Simulation strips correspond with aviation authorities requirements and recommendations, so the 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. It is clear that ice accretion can lead to large losses in lift, increases in drag and changes in the moments. Especially behaviour of the rolling and pitching moments is of great interest as they are connected closely with the control of aircraft in complex conditions.

Nomenclature

c	chord
C_L	lift coefficient
C_D	drag coefficient
C_l	rolling moment coefficient (based on wing span)
C_m	pitching moment coefficient (based on MAC)
C_n	yawing moment coefficient (based on wing span)
MAC	mean aerodynamic chord
Re	Reynolds number based on MAC
x_i	ice accretion position along chord
Δx_{AC}	displacement of aerodynamic centre
α (alpha)	angle of attack
η (eta)	elevator deflection
δ (delta)	aileron deflection
°	degree

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 moments 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. Similar phenomena concerning namely longitudinal control can occur with the ice accretion on the stabiliser.

Therefore, the investigation of ice accretion by the experimental or computational methods are important and conducted for many years.

Droplets of diameter of 2 to 50 micrometers are supposed to cause the conventional leading edge accretion, as specified in aviation authorities requirements. Supercooled large droplets of up to 500 μm can cause the ice accretion ridges formed out of leading edge. The mechanism of formation of supercooled large droplets and of formation of corresponding ice accretions was studied by Bragg [1-3].

The presented research followed the measurements of a two-dimensional airfoil section [8].

Wind tunnel model

The influence of ice accretion on an aircraft was measured on a model of a twin engine turboprop commuter with straight wing and T tail.

Two types of simulated ice accretion were examined. The V shape ice accretion strip was positioned at the leading edge of the wing or the stabiliser, the strip simulated conventional leading-edge ice accretion (Fig.1,2). The quadrantal strip at 5 %, 25% and 45 % of chord at the upper surface of the wing or the stabiliser simulated ice accretion caused by supercooled large droplets (Fig.3). The strip on the wing was positioned just ahead of the aileron (Fig.4). The deflections of the aileron were up to 22.5 degrees. The strip on the stabiliser was positioned along its whole span (Fig.4). The deflections of the elevator were up to 10 degrees down and 27 degrees up.

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 used wind tunnel was an atmospheric with open test section, of closed return type.

All tests were performed at the Reynolds number $0.6.10^6$. The angle of attack was changed from 0 up to the angle of maximum positive lift coefficient.

The aerodynamic coefficients measured such as lift coefficient, drag coefficient and moment coefficients were calculated by standard methods with conventional definitions.

The following configurations were measured:

- Aircraft without ice accretion. This configuration was provided as a reference baseline.
- Aircraft with ice accretion positioned at the wing ahead of the right aileron at 0% (V shape), 5%, 25%, and 45 % (quadrantal) of chord.
- Aircraft with ice accretion positioned at the stabiliser at 0% (V shape), 5%, 25%, and 45 % (quadrantal) of chord.

Results

Ice accretion at the wing

Lift, drag and pitching moment

All of the simulated ice accretions reduced lift curve slopes and reduced the maximum lift coefficient when compared with the clean aircraft case (Fig.5).

The presence of ice accretion shown in Fig.6 significantly increases drag in dependence on the ice accretion position.

The pitching moment exhibited in changing of the slope of moment curve. The moment curves are shown in Fig.7,8,9,10. Aircraft aerodynamic centre moved rearward at higher lift coefficients (Table 1).

Table 1
$\Delta x_{AC}/MAC$

C_L	Ice accretion position x_i/c			
	0	0.05	0.25	0.45
0,5-0,85	0,002	0,012	-0,015	0
0,85-1,05	0,050	0,041	0,032	0
1,05-1,20	0,049	0,031	0,030	0,020
1,20-1,35	0,068	0,034	0,055	0,024

Table 2
$\Delta x_{AC}/MAC$

C_L	Ice accretion position x_i/c			
	0	0.05	0.25	0.45
0,5-0,85	-0,066	-0,035	-0,033	-0,073
0,85-1,05	-0,044	-0,020	-0,041	-0,135
1,05-1,20	-0,084	-0,044	-0,044	-0,160
1,20-1,33	-0,106	-0,069	-0,068	-0,153

Rolling moment and efficiency of aileron deflection

The ice accretion significantly affected the aerodynamic derivative $C_{l\delta}$ defining a basic effect of aileron. The appropriate diagrams are in (Fig.11). The effect of the aileron deflection was reduced by moving the ice accretion toward 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.

The ice accretion at leading edge could create such significant rolling moment that full deflections of the ailerons were necessary to compensate it (Fig.12).

Ice accretion at the stabiliser

Lift and drag

All of the simulated ice accretions reduced slightly lift curve slopes and reduced the maximum lift coefficient (Fig.13). The presence of ice accretion also significantly increased the drag in dependence on ice accretion position, the phenomenon was the strongest for the accretion on and near the leading edge (Fig.14).

Pitching moment and efficiency of elevator deflection

The presence of the accretion resulted in significant change of the slope of moment curve. The moment curves are shown in Fig.15,16. Aircraft aerodynamic centre moved forward particularly at higher lift coefficients (Table 2).

The ice accretion significantly affected the pitching moment coefficient at the constant deflection of elevator. The change of the angle of attack could reach up to 4 degrees, the angle could increase or decrease in dependence of the elevator deflection.

The ice accretion reduced the efficiency of the elevator deflection, i.e. the aerodynamic derivative $C_{m\eta}$ defining a basic effect of elevator was reduced. The appropriate diagrams are in Fig.17. The effect of the elevator deflection was reduced by moving ice accretion toward the leading edge. Similarly to the aileron case, the phenomena were relatively significant also for ice accretion at 25 % and 45 % of chord, where the usual devices for ice accretion elimination are not effective.

Conclusions

An experimental investigation was conducted to study the aerodynamic effect of simulated ice accretion corresponding with aviation authorities recommendations. The presence and location of ice accretion significantly affected important aerodynamic characteristics of an aircraft. Special attention was paid to the characteristics important for the control of the aircraft such as aileron, horizontal tailplane and elevator efficiency.

The following conclusions can be drawn.

- Ice accretion affects all aerodynamic forces and moments.
- The influence of ice accretion is increased by move toward the leading edge, the strongest

consequences are caused by the conventional leading-edge accretion.

- In the case of accretion ahead of aileron, the rolling moment is significantly changed; it could be changed to the extent that it could not be compensated even by full aileron deflection. The efficiency of aileron deflections is deteriorated and $C_{L\delta}$ falls.
- In the case of accretion at the stabiliser, the pitching moment is significantly influenced as well as the position of aerodynamic centre of aircraft. The efficiency of elevator is deteriorated. A combination of limited stability and controllability with worse lift and drag characteristics can create potentially dangerous situations.

Acknowledgements

The project was supported by Ministry of Education, Youth and Sport of the Czech Republic and by VZLU Aeronautical Research and Test Institute in Prague. The authors acknowledge the help and support given by the leadership of the institutions.

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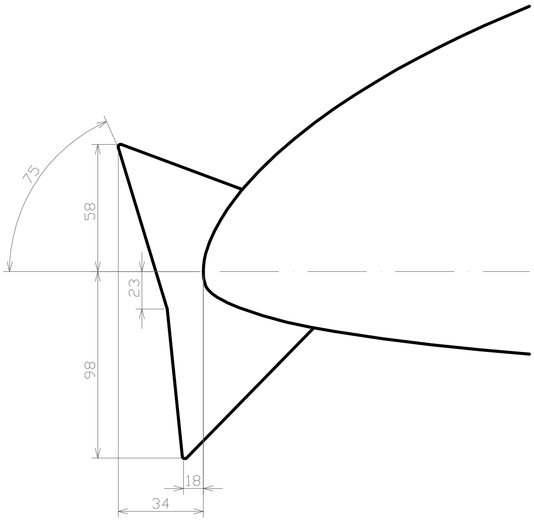


Fig.1 Wing V shape ice accretion strip

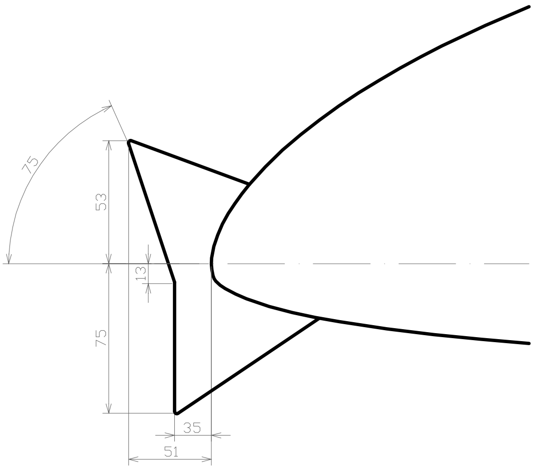


Fig.2 Stabiliser V shape ice accretion strip

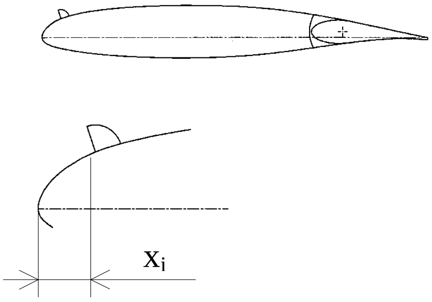


Fig.3 Quadrantal ice accretion strip

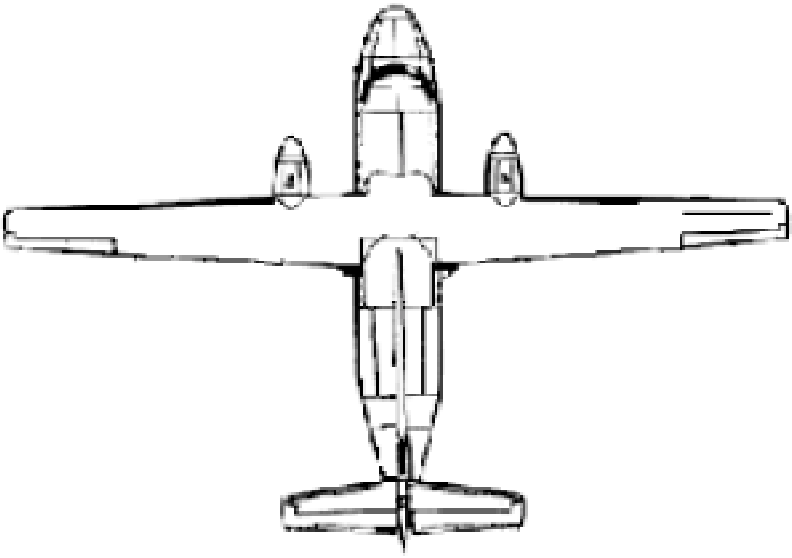


Fig.4 The ice accretion strip positioned at the right wing and the stabiliser

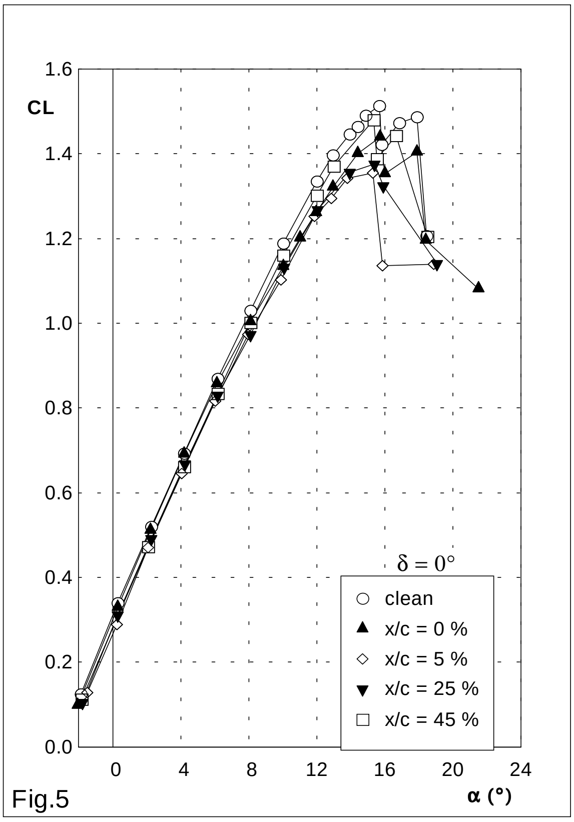


Fig.5

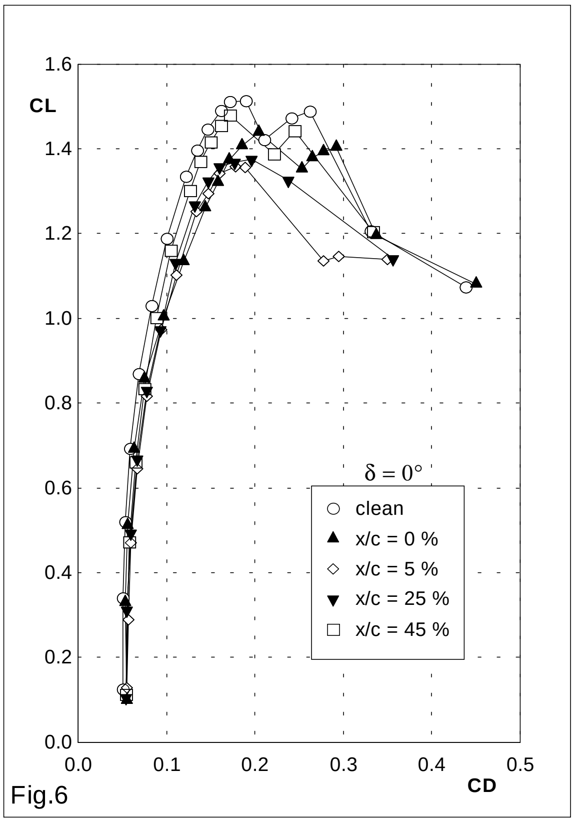


Fig.6

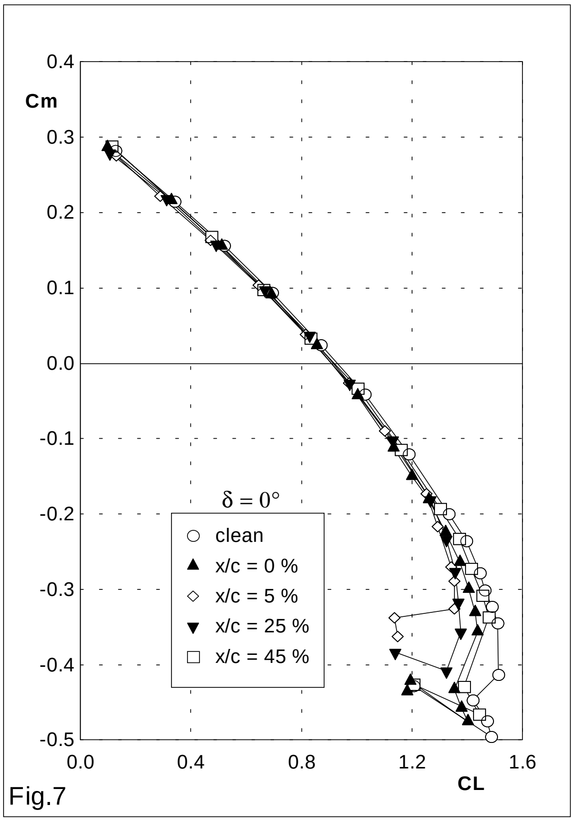


Fig.7

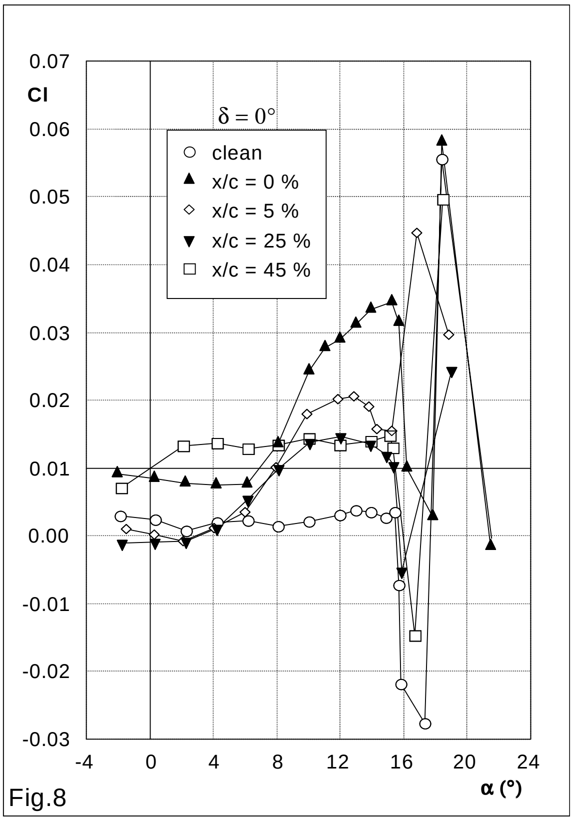


Fig.8

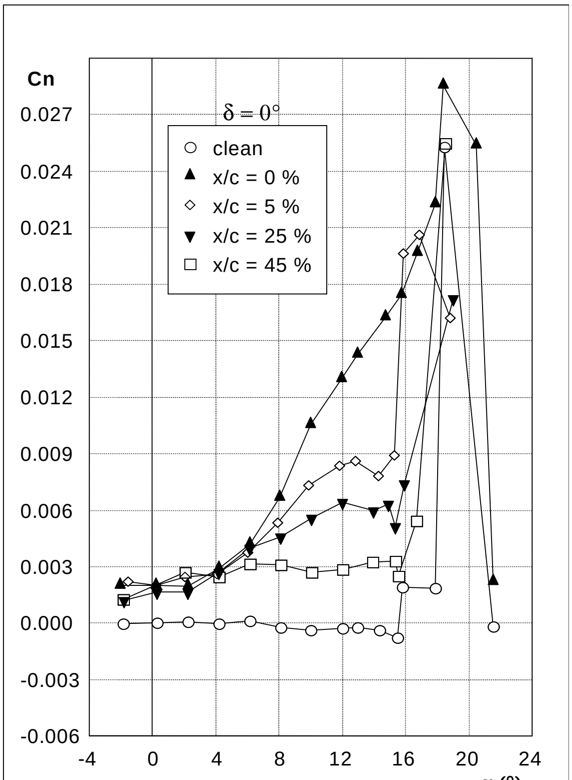


Fig.9

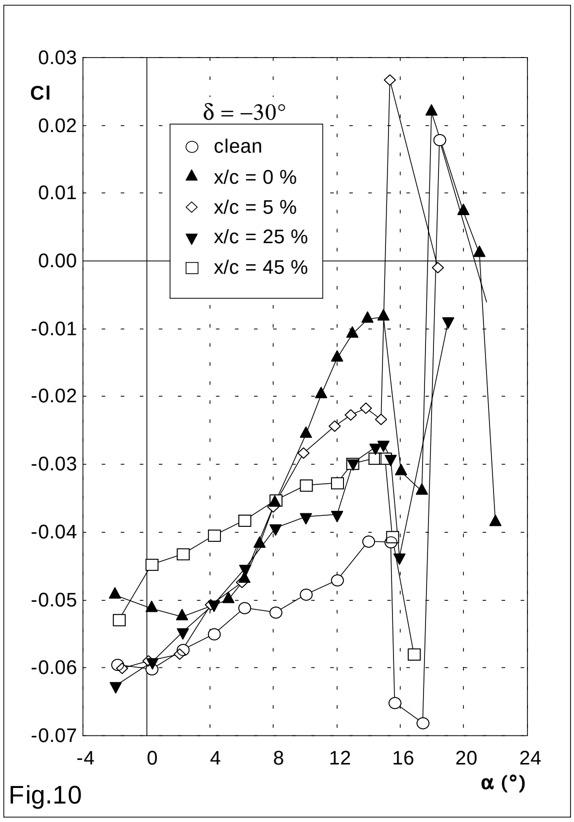


Fig.10

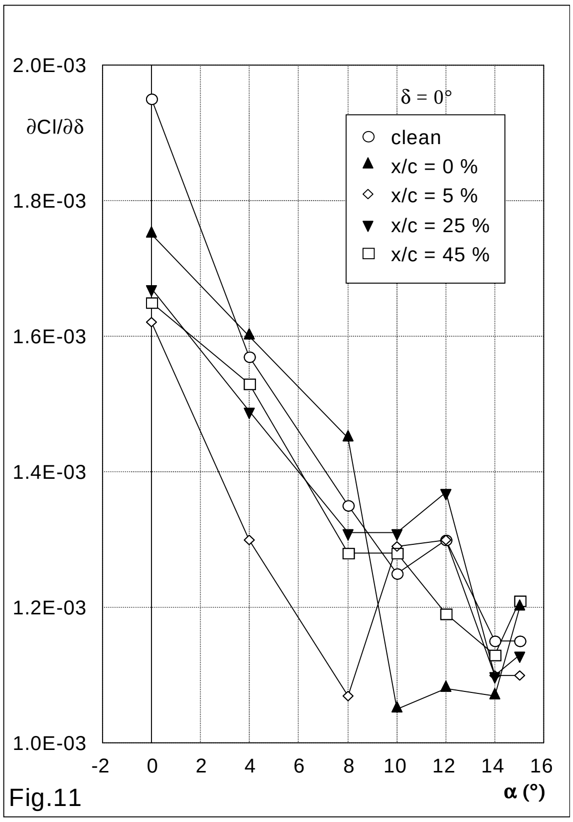


Fig.11

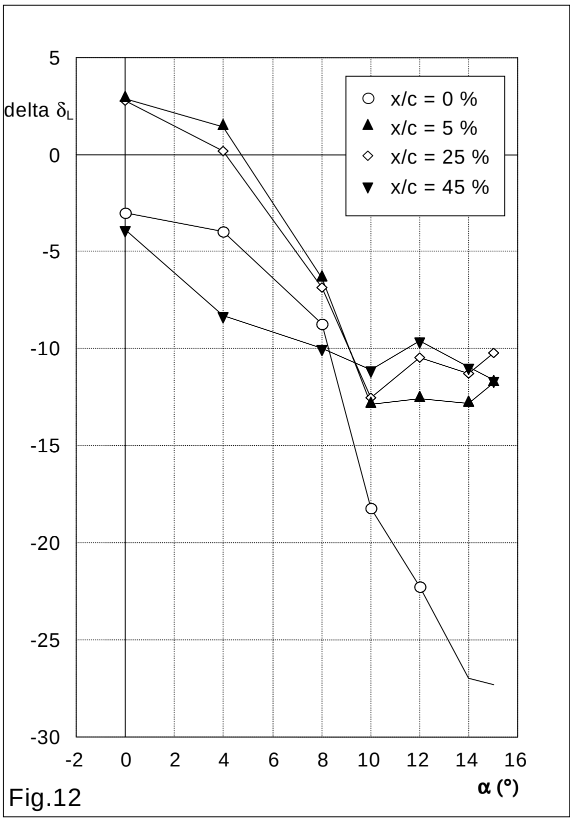


Fig.12

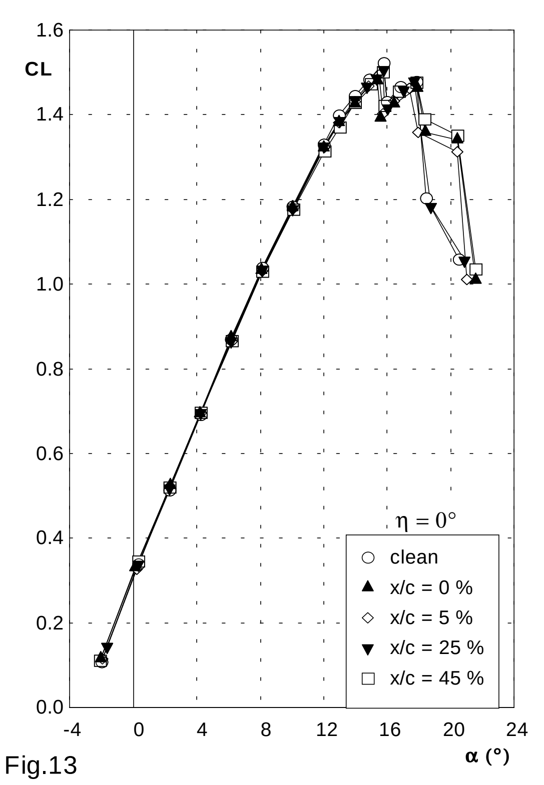


Fig.13

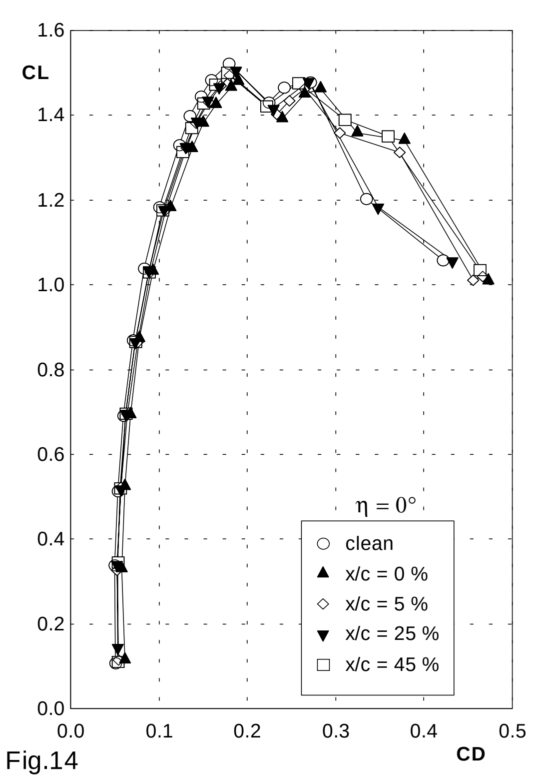


Fig.14

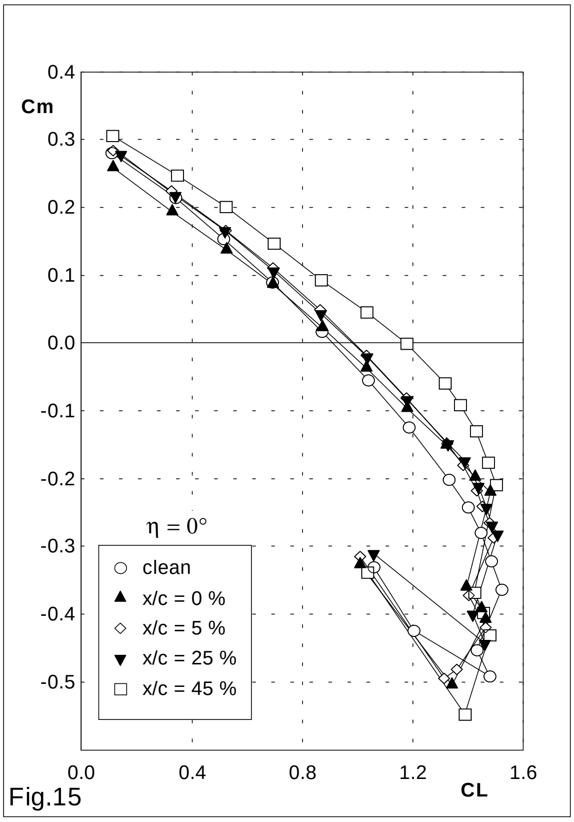


Fig.15

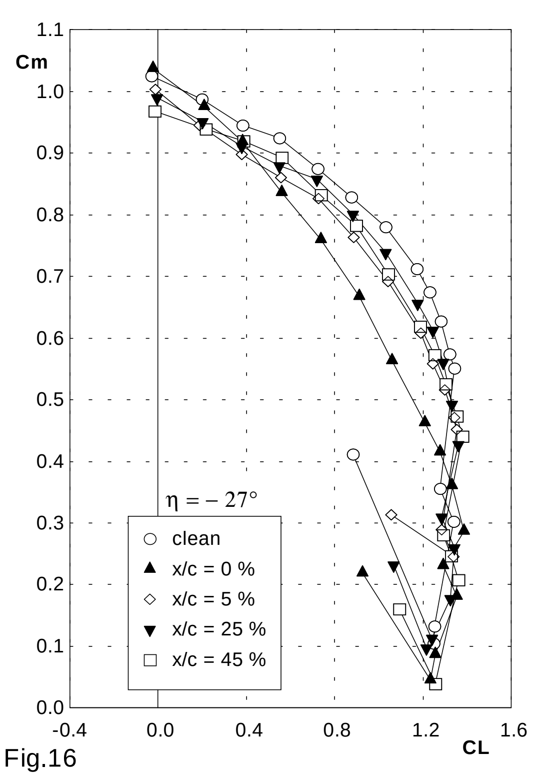
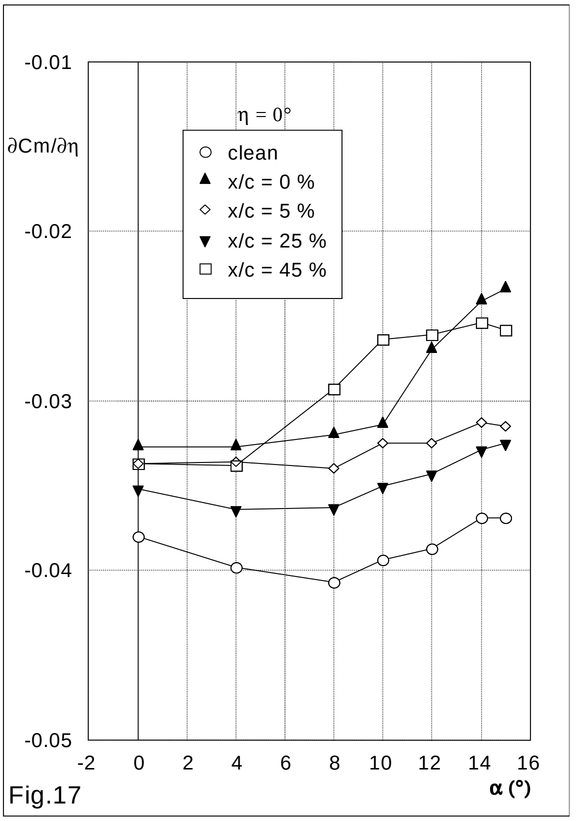


Fig.16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-0.02
-0.03
-0.04
-0.05
∂Cm/∂η
η = 0°
○ clean
▲ x/c = 0 %
◇ x/c = 5 %
▼ x/c = 25 %
□ x/c = 45 %
-2
0
2
4
6
8
10
12
14
16
α (°)

Fig.17