Review

General comments

The authors present an experimental/computational study on the influence of ice accretion on the NREL S826 airfoil. The analysis considers steady and bidimensional conditions. The issue is relevant but several major modifications and additional work are proposed before taking a decision to consider the manuscript for publication.

I have three main concerns:

- In my opinion (and if you consider that I am wrong, please comment on that) the analysis of the influence of ice accretion on the aerodynamic performance of an airfoil has relevant stochastic characteristics. I suppose that the ice shapes, for given conditions (air speed and temperature), can vary, following a stochastic pattern, and therefore the disturbed $c_l(\alpha)$ and $c_d(\alpha)$ functions are stochastic functions. The authors should consider the possibility to do some statistic analysis by generating different ice shapes and the corresponding $c_l(\alpha)$ and $c_d(\alpha)$ functions. In other words, how representative are the modified $c_l(\alpha)$ and $c_d(\alpha)$ functions that you have obtained since they correspond to a single test case?. I understand that testing several models in the wind tunnel is expensive but once you have confidence in your RANS model, to do numerical test is really cheap.
- Two relevant airfoil parameters when analysing the optimum performance of a wind turbine are the airfoil aerodynamic efficiency, $k(\alpha)$, and the optimum angle of attack, α_{op}. There is not any comment on these parameters. The authors should analyse these parameters.
- Transforming the modification in $c_l(\alpha)$ and $c_d(\alpha)$ (and therefore $k(\alpha)$) into changes in the $C_P(\lambda, \theta_C, \mathrm{Re})$ map of the rotor is very relevant, and it is even more relevant when the authors continuously refer to the effect of the modification in $c_l(\alpha)$ and $c_d(\alpha)$ on the rotor performance and the authors refer to such type of quantification from other authors. They should include their own quantification.

Abstract

"...with a lift reduction of up to 30% in the linear lift area..." by "...with a lift reduction of up to 30% in the linear lift coefficient region...".

What about aerodynamic efficiency and optimum angle of attack?.

1.1. Background

I miss a reference to EU project WIND ENERGY PRODUCTION IN COLD CLIMATE (WECO).

"For wind turbine operation, there are several problems related to icing." by "There are several problems related to icing for wind turbine operation."

"Increased risk of structural fatigue,..." by "Increased levels of structural fatigue,..."

"...safety hazards of ice throw, electrical and mechanical failures..." by "safety hazards of ice throw and electrical and mechanical failures...".

"...Icing can also lead to overproduction and thus excessive structural loads, due to sudden increase in momentum, which the wind turbine is not dimensioned for (Jasinski et al., 1998)." Please explain a bit more (an additional sentence is enough). Is the mentioned overproduction due to increased air density?

"Further development in computational fluid dynamics, through experimental validation, will make information more available and less expensive to obtain when evaluating new challenges.". Too ambiguous sentence. What are the mentioned new challenges?.

1.2. Objective

"Their effects on aerodynamic properties were investigated." Please be more specific, describe from the very beginning which parameters will be analysed.

2. Method

"The blade tip is the part that is most exposed to icing due to large tip velocities leading to high accumulation rates." Since you are presenting a very general description of the ice accumulation phenomenon, a reference on this issue would be welcome here.

"...a hydraulically smooth surface was used for the experiments (Aksnes, 2015)". Have you calculated any kind of friction Reynolds number to state that your surface is hydraulically smooth?.

2.1. Defining Icing Cases

"...in the code are not excluding low-Reynolds numbers...". Please indicate here what is the range of Reynolds numbers in your test.

"...therefor..." by "...therefore...".

"...t_{icing}..." by "...t_i...". Check the whole document.

"Three ice shapes were selected, which are mainly distinguished by the temperature at which they form." This process probably has a high stochastic nature, so that, for given values of V_∞ and T, the ice shapes are different from one experiment to another. This stochastic nature should be considered, if not, you are presenting a single case study that could no be representative (in the statistical sense).

Table 1. $V_\infty = 25$m/s, 40m/s values seem to be small compared with typical blade tip speed values. Why these small values are chosen?

"The surface roughness ks for each icing case..." is k_s the equivalent sand-grain roughness? please clarify.

2.2. Experimental Setup

"A_{wing}/A_{tunnel}" by "A_W/A_T".

Figure 2. Enhance quality of text and lines on the figure (a).

2.3. Measurement Methods.

"To determine the lift and drag of the wing, force- and pressure measurements were applied." this isolated sentence here does not fit well.

"For all test cases, including with icing, the area was calculated using the clean wing chord length." Is this precise enough? you are not measuring a 2% or 5% of the chord where high suction values can occur. Also the real chord is 2% to 5% larger, what means differences in c_d of this order of magnitude for the different ice/no ice cases (this is the order of the differences that you are presenting in your figures for c_d in the linear region for c_l. Please comment on this.

"Normalized pressure, Cp, was..." by "Pressure coefficient, C_p, was..."

"...obtained surface pressure distributions exclude the measurements from these taps." Comment of the related error (see my comment at the beginning of this section).

Expression (3). Please include the integration limits.

"...velocity and y is the width..." by "...velocity and y is the width..."

Expressions (4) and (5) not in line. p_0 is clear in the mentioned expressions but which speed is u?.

"This means up to around 12º for the clean airfoil, and less for the icing cases depending on the shape." The term "less" is too vague, please be more specific.

"Uncertainty estimations show an offset of approximately $C_D = 0.01$ in the calculated drag, over the applied range of AoA, due to static pressure effects." Please quantify the associated uncertainty in the maximum aerodynamic efficiency.

2.4. Simulation Setup.

"...a state-of-the-art Navier-Stokes CFD solver..." Are you using RANS, LES? please clarify from the very beginning.

3. Results and Discussion

"However, the objective of this study is to discover general trends of icing impact on aerodynamic performance, so the Re mismatch is considered to be not significant." I would not state that since your are testing in a Reynolds number region where the aerodynamic coefficients are quite sensitive to the variation of this non-dimensional number. So, I would say that the influence of Reynolds number mismatch deserves further research efforts that are out of the scope of this work.

"In the linear area..." by "In the linear region..."

"The current study shows that mixed ice causes more severe performance losses than rime- and glaze ice, leading to the assumption that less streamlined ice shapes can reduce power output even more." Why not concluding on variations of c_l, c_d and k instead of directly concluding on the effects on the wind turbine power output, without any calculation?. I would compare your results on variations of c_l, c_d and k with the results of other authors, and then, and only then, I would translate my conclusions to the influence on the rotor performance parameters (power coefficient, equivalent loads...) after performing my own aeroelasic analysis of the rotor equipping the ice covered airfoils.

"Mixed ice is,..." by "Mixed ice case is,..."

"In this area, the..." by "In this region, the..."

"...ice curves start to incline..." please rephrase this sentence.

"The lift decrease and drag increase that can be observed for all ice shapes indicate that icing generally leads to reduced performance and hence power output losses." It is true, but is too vague, quantify the variation in the aerodynamic efficiency and then in power coefficient.

Figure 3. Include similar figures for the aerodynamic efficiency. You are showing differences for c_d in the linear c_l region less than 0.01 which is the uncertainty of your c_d measurements due to p_0 hypothesis. You should consider the bias associated to consider the clean airfoil chord value to calculate coefficients for all the cases.

3.2 Prediction of Airfoil Coefficients by FENSAP-ICE

"Computational lift values show good..." by "Lift coefficient values provided by the computational model..."

..."experimental values in the linear area..." by "experimental values in the linear region..."

"...while it deviates more around stall occurrence..." by "...while larger differences are found in the stall region..."

"The curves, however, display a large resemblance." by "Trends are well predicted.".

"The computational drag values follow..." by "The drag values predicted by the computational model follow..."

"...for all the icing cases before stall occurs..." by "...for all the icing cases out of the stall region..."

"Deviations in this area is expected,..." by "Deviations in this region are expected,..."

"The deviations seen..." by "The deviations observed..."

"The Spalart-Allmaras turbulence..." by "Firstly, the Spalart-Allmaras turbulence..."

"...assumes fully turbulent flow." by "...assumes fully turbulent flow, and therefore laminar-turbulent transition is not predicted".

"For the complex shapes studied, at AoAs..." by "Secondly, for the complex shapes studied, at AoAs..."

"...the aerodynamic characteristics are affected in ways that are not necessarily captured by a simplified turbulence model." Too vague, please specify a bit more. Include a relevant reference on this issue.

3.3 Surface Pressure Distributions

"...lift vulnerable to disturbances in this area." by "...lift vulnerable to disturbances in this region".

"...over the ice shape." by "on the ice shape on the upper side of the airfoil."

"...by the relatively constant C_P in this space..." by "...by the relatively constant C_p in this region..."

About the comparison between computational and experimental results. Since you quantify differences between wind tunnel and computational results in your analysis, I recommend to present a figure showing such differences instead of forcing the reader to calculate these differences on line.

"One reason for this is likely the earlier onset of trailing edge separation on the suction side when icing is present, making it difficult to predict pressure correctly by the turbulence model." This is a bit confusing considering your previous arguments. You stated that the weak point of your RANS model is that it considers fully turbulent conditions and, therefore, transition is not predicted. Now, when ice formations exist guarantying fully turbulent conditions downstream the leading edge, you state that this is a weak point of your model. Please clarify a bit more what are the weak points of your computational model. For sure there are excellent works of other authors analysing the drawbacks of RANS models when predicting flow behaviour around airfoils. I recommend to refer to them.

"All three icing shapes are likely to trigger laminar..." by "All three icing shapes are likely to trigger laminar-turbulent..."

Why do you add results from XFOIL?, what is the contribution?

Check formats: "x/c" instead of x/c...Please review the whole paper.

What does "SP" mean?

"...it is not able to capture laminar transitions..." by "...laminar-turbulent transitions are not captured..."

"In addition, low flow velocities experience higher relative disturbances, adding uncertainty to the measurements." Explain a bit more. Add a reference.

A really linear $c_l(\alpha)$ region is not detected in your figure 8 (there is a clearly detectable curvature in the $c_l(\alpha)$ curve for $\alpha \in [-5, 5]$deg. Why? Compare with other authors [1]. Is the S806 airfoil an airfoil not exhibiting a linear $c_l(\alpha)$ region?.

3.4 Reynolds Number Dependency

"Ice accretion show..." by "Ice accretion shows..."

"...which will lead to rotational losses.." What are "rotational losses"?

The influence of Re is really small for the range of Re values explored. Please compare your results with results of other authors, other airfoils.

4. Conclusions

"The rime- and glaze ice shapes investigated had a similar impact on the performance, both quantitatively and qualitatively. In the typical operating range, lift was reduced by 10% and drag increased by 80%." In which α range?

"In the area before stall, lift..." by "In the regions before stall, lift..."

"In the area before stall, lift was reduced by 30% and drag was increased by 340%." specify α range.

"All ice types lead to performance losses of a magnitude that will reduce power output significantly." Please use quantitative conclusions. Calculate the effect on aerodynamic efficiency and power coefficient if you pretend to present conclusions on the influence in the rotor performance.

"The deviations are most pronounced after stall, leading to the assumption that they could be related to inaccuracies in the turbulence model and the absence of a transition model." Please support this conclusion on an evidence or on the work of other authors.

"...great potential in applying CFD icing methods..." CFD icing method is confusing, please rephrase the sentence.

"Further investigation on impact of ice extent, both in span and chord directions, would provide useful insight to the total effect of icing on a wind turbine installation." Vague conclusion. Please be more specific, what about the stochastic nature of the ice formation process?.

References

[1]. H. Sarlak , R. Mikkelsen, S. Sarmast, JN. Sϕrensen, Aerodynamic behaviour of NREL S826 airfoil at Re=100,000, Journal of Physics: Conference Series 524 (2014) 012027