



Parametric approximation of airfoil aerodynamic coefficients at high angles of attack

Skrzypinski, Witold Robert; Zahle, Frederik; Bak, Christian

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Abstract

Three methods for estimating the C_l and C_d curves at high AOAs were analyzed in this work. A method utilizing even sine and cosine functions was further developed. It was determined that between 160° and -160° AOA, the aerodynamic coefficients may be obtained with computationally inexpensive steady 2D CFD. In this work, reference aerodynamic coefficients were used directly at those AOAs. Reference aerodynamic coefficients were also used directly at AOAs between -30° and 30° as in this region the data is typically either available or may be obtained with computationally inexpensive 2D CFD. At other AOAs, the present approximation method produced C_l , C_d , and C_m curves satisfactorily close to the reference.

Introduction

Authors dealing with wind turbine blade stability at standstill conditions [1,2,3] indicate that the aerodynamic damping of blades at high AOAs is dependent on their aerodynamic characteristics. Often, those characteristics are assumed to be as of a flat plate. According to [1,2], a more accurate representation of airfoil characteristics at high AOAs may be necessary to tackle the problem of aerodynamic stability at standstill conditions. This work presents an attempt to approximate airfoil aerodynamic coefficients at high AOAs.

Methods

Three methods for approximating aerodynamic coefficients at high AOAs (incl. flat plate) [4,5] were verified against the 360° wind tunnel measurements of the DU96-W-180 airfoil [6,7]. The best method [4] was chosen and modified in order to produce a satisfactory approximation of airfoil aerodynamic coefficients in the whole AOA range with the lowest possible number of data points necessary to tune the model. Further, a method for the approximation of C_m similar to [4] was found. Additionally, a range of AOAs in the vicinity of 180° was found at which the aerodynamic coefficients may be obtained with computationally inexpensive steady 2D CFD. This was done by a comparison of the results obtained with 2D steady CFD [8,9,10] with the results obtained with unsteady 3D CFD [8,9,10]. Note that obtaining the aerodynamic characteristics in the AOA range approximately between -30° and 30° is easy as this data may be computed with 2D CFD or is typically available from wind tunnel measurements. Therefore, this AOA range is outside the scope of the present work. On the other hand, accurate prediction of airfoil aerodynamic characteristics at high AOAs by means of CFD or wind tunnel measurements proves difficult. CFD computations capable of resolving the physics of flows at high AOAs are 3D and computationally expensive. This increases the need for an engineering model capable of delivering reliable airfoil characteristics at high AOAs by using a relatively low number of reference data points obtained by 3D CFD or cautious wind tunnel measurements.

Results

In this work, it was shown that the aerodynamic characteristics in the vicinity of 180° AOA may be computed with 2D CFD, because the flow in this AOA region is partly attached. Figure 1 presents a comparison of 2D steady CFD computations carried out between 150° and -150° AOA with 3D unsteady DES CFD computations carried out at 163° , 169° and 180° AOA, on an extruded airfoil [11], at $Re=12e6$. The comparison was satisfactory, as the C_l and C_d values computed with 3D CFD were relatively close to the respective curves obtained by means of 2D CFD. Because of that, in the present work the reference measurement data was used directly not only between -30° and 30° AOA but also between 160° and -160° AOA. It is also recommended that those AOA regions are computed using 2D CFD when 360° aerodynamic characteristics are approximated in the future using the present method.

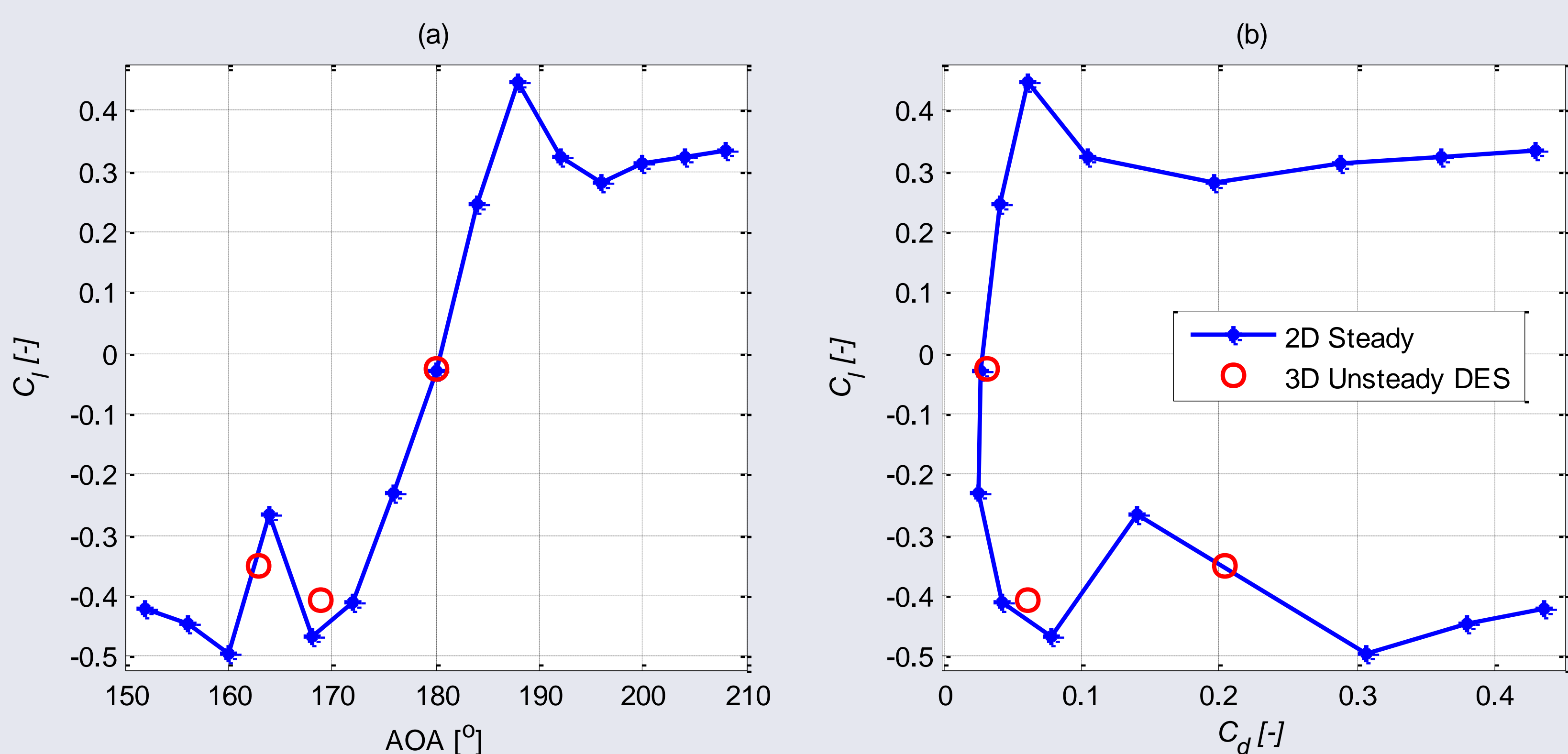


Figure 1: Comparison of 2D steady CFD computations carried out between 150° and -150° AOA with 3D unsteady DES CFD computations carried out at 163° , 169° and 180° AOA.

The equations from [4] were chosen for further investigation, with the even sine approximation for C_l , and even cosine approximation for C_d . The most effective approach to capture the different maxima in the positive and negative AOA regions of both C_l and C_d curves was to find independent approximations for the curves in both regions, and blend them with the characteristics used directly in the AOA regions between -30° and 30° as well as between 160° and -160° .

The results of such approximations for C_l and C_d are presented in Figure 2 and Figure 3, respectively. A satisfactory estimation of the C_l curve was obtained with four data points used to tune the model on each side of the y axis. At the right side of the y axis, those points were at AOAs equal to: 30° , 45° , 105° and 135° . On the left side of the y axis, the points were placed symmetrically. If points at the same AOAs were used to approximate new airfoil coefficients, three points at each side of the y axis would need to be computed using 3D CFD whereas at -30° and 30° AOA, 2D CFD would likely be sufficient. In order to approximate the C_d curve, three points at each side of the y axis were used: 30° , 45° and 105° on the right side, and symmetrically on the left.

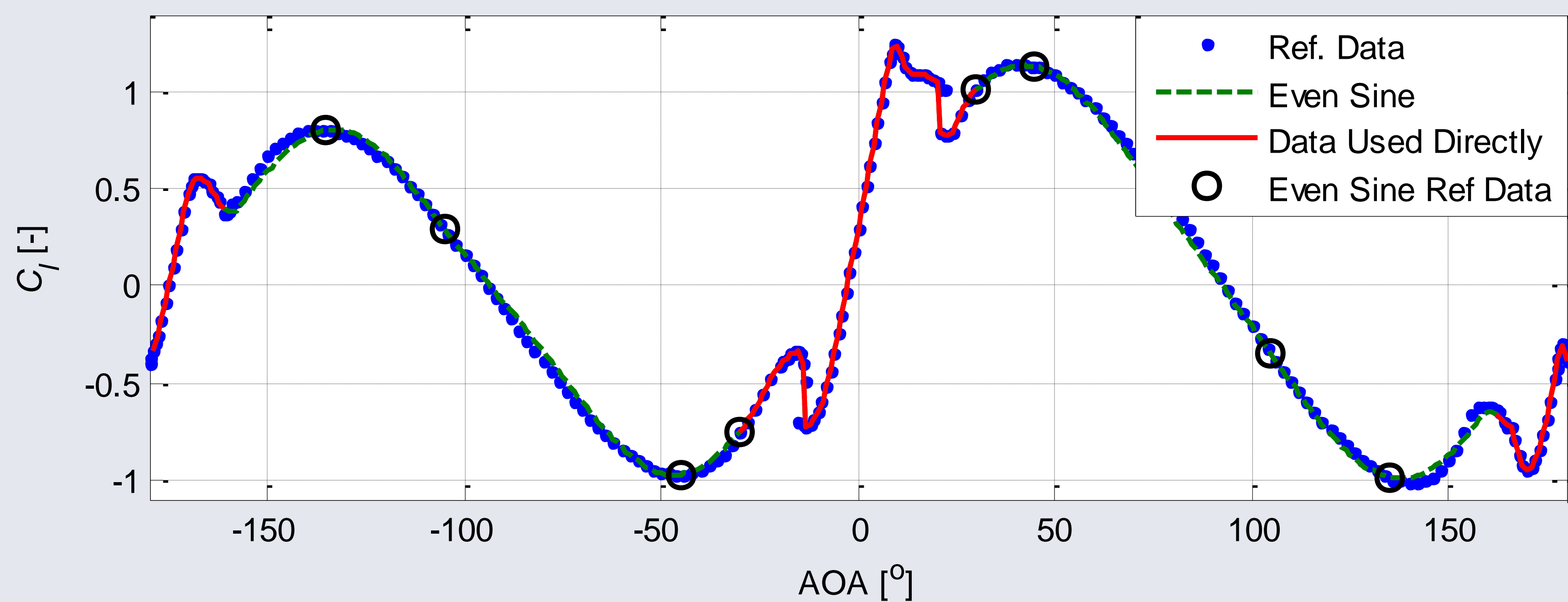


Figure 2: Even sine approximation of C_l , blended with the reference data [6,7] for AOAs between -30° and 30° , and between 160° and -160° ; 'Even Sine Ref Data' shows the points used for tuning the model

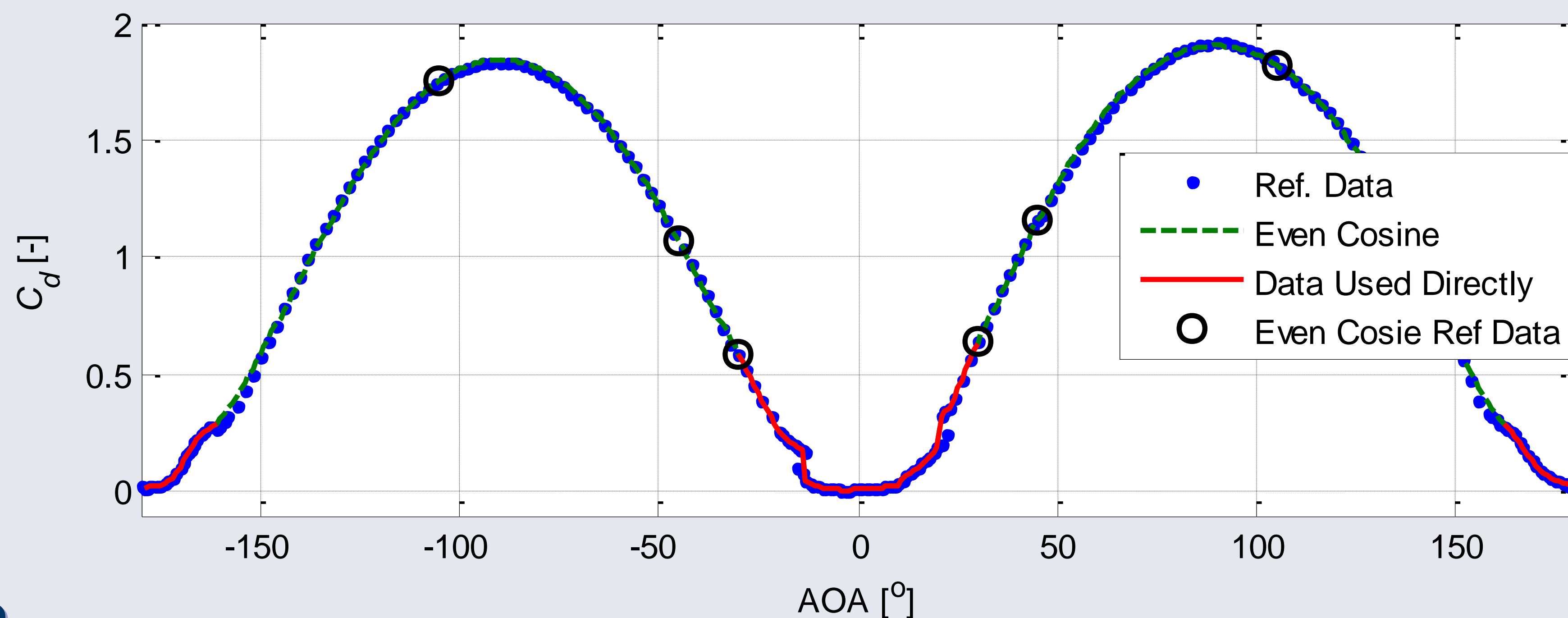


Figure 3: Even cosine approximation of C_d , blended with the reference data [6,7] for AOAs between -30° and 30° , and between 160° and -160° ; 'Even Cosine Ref Data' shows the points used for tuning the model

Conclusions

Three methods for estimating the C_l and C_d curves at high AOAs were analyzed (incl. flat plate) [4,5]. The methods were validated using the aerodynamic coefficients of the DU96-W-180 airfoil [6,7]. The method [4] was further developed by using two independent harmonic approximations in the positive and negative AOA regions for the estimation of C_l and C_d . Original data was used directly in the AOA region between -30° and 30° as well as between 160° and -160° AOA. In order to use original data between 160° and -160° and thereby assume that in the future this AOA region would be computed with 2D CFD, a comparison of the results obtained with 2D and 3D CFD in the aforementioned AOA region was carried out. The method produced satisfactory results for the C_l , C_d and C_m curves in the whole AOA range by using five data points to tune the model on each side of the y axis. In case of a new approximation, three points at AOAs equal to 45° , 105° and 135° would need to be computed using 3D CFD while the points at 30° and 160° could be obtained using 2D CFD.

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