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Airfoil Lift and Drag Extrapolation with Viterna and Montgomerie Methods

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Abstract

In order to compute the performance of a propeller blade using blade element momentum (BEM) method, the two-dimensional airfoil performance of the propeller blade in terms of lift and drag coefficients is necessary. Such data usually can be obtained from model experiment only for limited range of angle of attack (AoA). Therefore, it is necessary to extrapolate the limited experimental data to obtain the data for the whole range of AoA. The present study uses 2 (two) methods which are Viterna and Montgomerie methods in order to extrapolate the performance of an airfoil. The formulas and procedures of both methods are presented and their application are also demonstrated using an airfoil shape of NACA23012. From this study, a relatively good agreement of the airfoil performance in terms of lift and drag coefficients can be found from computation results of the both methods.

Keywords: Airfoil Performance; Data Extrapolation; Montgomerie method; NACA23012; Viterna method

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Nomenclature

AR	aspect ratio	C_{Lstall}	lift coefficient in stall condition
C_D	drag coefficient	f	transformation function
C_{Dmax}	maximum drag coefficient	t	straight line function
C_{Dstall}	drag coefficient in stall condition	α	angle of attack
C_L	lift coefficient	α_{stall}	angle of attack in stall condition

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1. Introduction

There are numerous approaches and methods which can be used to compute a wind turbine performance. Although computational fluid dynamics (CFD) method could deliver the most accurate results, it has extremely high computational cost, analysis time, and required expertise. Considering these factors, blade element momentum (BEM) method remains to be the most widely method for predicting wind turbine performance.

The BEM was first formulated by Glauert [1] to analyze airplane propeller performance. In using the BEM, the propeller blade is divided into several elements, which act as two dimensional (2D) airfoil. The forces and moments are computed on each element and the total forces and moments are determined by integrating the forces and moments on these elements. Moreover, several corrections need to be implemented in order to make it applicable in designing wind turbine blades such as tip loss correction, hub loss correction, etc.

Therefore, in order to compute the turbine blade performance using the BEM method, the performance in terms of lift and drag coefficients of each blade element (airfoil) is necessary. The data are usually obtained from model experiment. However, the experiment can only be conducted for a limited range of angle of attack (AoA). Consequently, it is necessary to extrapolate the initial data obtained from experiment in order to obtain the lift and drag coefficients for whole range of AoA.

In the present study, 2 (two) methods are used to extrapolate the experimental data, which are Viterna and Montgomerie methods. Both methods are the most common methods adopted for airfoil experimental data extrapolation. Viterna method was formulated based potential flow theory and it is simpler than Montgomerie method [2]. However, even though more complicated than Viterna method, Montgomerie method has been shown to have higher accuracy than Viterna method [3].

For demonstrating the computation procedure, an airfoil shape of NACA23012 is used. The initial data of lift and drag coefficients are taken from available experiment data. Using the initial data, the adopted methods are used to perform extrapolation in order to obtain the coefficients for the whole range of AoA. Discussion on the results comparison are presented and discussed.

2. Computational Methods

2.1. Viterna Method

Viterna method is one the most popular methods in extrapolating airfoil data. In order to use the Viterna method, an existing set of airfoil data is necessary. The data can be obtained from experiments or numerical computations. Using the data, the extrapolation of the data from α_{stall} to 90° is performed using the following equation [4]:

$$C_L = A_1 \sin 2\alpha + A_2 \frac{\cos^2 \alpha}{\sin \alpha} \tag{1}$$

$$C_D = B_1 \sin^2 \alpha + B_2 \cos \alpha \tag{2}$$

Where

$$C_{D_{max}} \simeq 1.11 + 0.018AR \tag{3}$$

$$A_1 = \frac{C_{D_{max}}}{2} \tag{4}$$

$$B_1 = C_{D_{max}} \tag{5}$$

$$A_2 = \left(C_{L_{stall}} - C_{D_{max}} \sin\alpha_{stall} \cos\alpha_{stall}\right) \frac{\sin\alpha_{stall}}{\cos^2\alpha_{stall}} \tag{6}$$

$$B_2 = \frac{C_{D_{stall}} - C_{D_{max}} \sin^2\alpha_{stall}}{\cos\alpha_{stall}} \tag{7}$$

The symbol AR in Eq. (3) stands for aspect ratio which can be obtained from the BEM method application where finite blade length affects the flat plate assumption. The recommended value for AR is 10 for most computations. However, using different value of AR will make little impact on the final results. In extrapolating data for $\alpha > 90^o$ and $\alpha < \alpha_{min}$, the calculated values are reflected. The Viterna method does not make any considerations to solve pressure or skin friction forces distribution; however, by making a few simple assumptions it is possible to provide a reasonable estimate which agrees with the results predicted using the Viterna method [5]. Even though the method computation results are not an accurate representation of the true physics, it could provide a reasonable estimate for early in the design process.

2.2. Montgomerie Method

In extrapolating the lift and drag coefficients of an airfoil, Montgomerie method is also one of the popular methods. Montgomerie method is formulated based on the assumption that there exists some potential-flow-like behavior in a real airfoil around 0^o angle of attack. At higher angles of attack, the airfoil performance behaves like a basic thin plate. For the intermediate angles, a transformation function f is used to simulate the behavior. The total performance is an interpolation between the thin plate behavior (s) and the potential flow curve (t), which can be described using the following formula [6]:

$$C_L = f \cdot t + (1-f)s \tag{8}$$

Where t is the straight line function being a tangent to the C_L curve at (α=0, C_L=C_L(0)). The transformation function f is determined from the original C_L vs α curve. The function is now can be calculated using the following expressions:

$$f = \frac{1}{\left(1 + k \cdot \Delta\alpha^4\right)} \tag{9}$$

Where

$$k = \left(\frac{1}{f_2} - 1\right) \frac{1}{\left(\alpha_2 - \alpha_m\right)^4} \tag{10}$$

The point α_m is defined as the angle where C_L curve starts to deviate from the potential curve t. It can be computed using the following expression:

$$\alpha_m = \frac{\alpha_1 - G\alpha_2}{1 - G} \tag{11}$$

Where G is defined as:

$$G \equiv \sqrt[4]{\frac{\frac{1}{f_1}-1}{\frac{1}{f_2}-1}} \tag{12}$$

3. Airfoil Data

The computed airfoil in the present study is NACA23012. The shape of the airfoil is shown in the following figure.

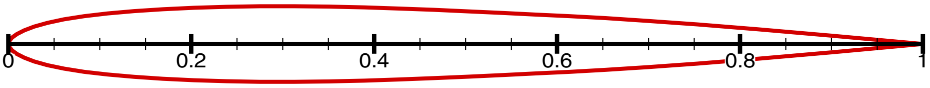
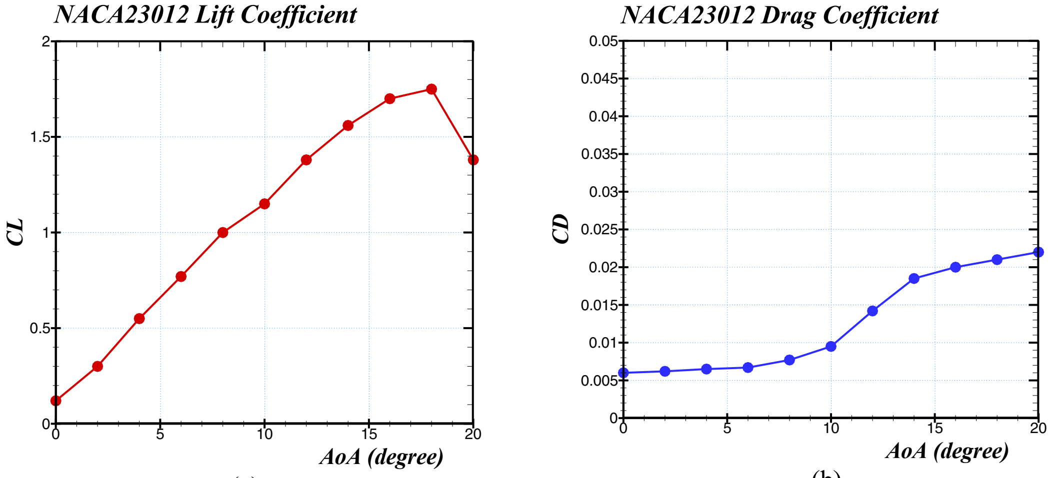


Fig. 1. NACA23012 airfoil shape

The lift and drag coefficients of the airfoil can be found in reference [7] for a limited range of angle of attack. They are shown in the following figure.



(a) (b)

Fig. 2. Performance of NACA23012 from model experiment, (a) Lift coefficient, (b) Drag coefficient

4. Computational Results and Discussions

4.1. Lift Coefficients

Using the model shape shown in the previous section, computations are performed to extrapolate the limited range of the initial available data using Viterna and Montgomerie methods. The computation results are shown in the following figure

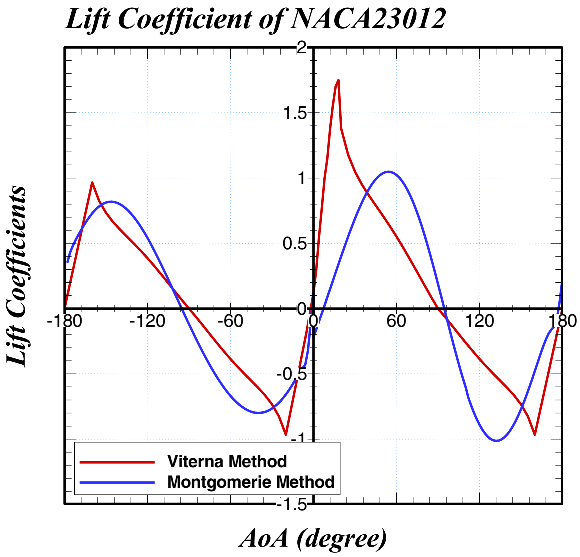


Fig. 3. Lift Coefficients of NACA23012 obtained from extrapolation with Viterna and Montgomerie Methods

From the figure, it can be shown that the C_L curve computed using Montgomerie method has more sinusoidal shape while it can been the peak of the C_L curve computed with Viterna method. This is because of the potential flow theory assumption used in Viterna method [2].

4.2. Drag Coefficient

The computations are also performed to extrapolate the lift and drag coefficients of NACA23012 using Viterna and Montgomerie Methods. The computation results are shown in the following figure

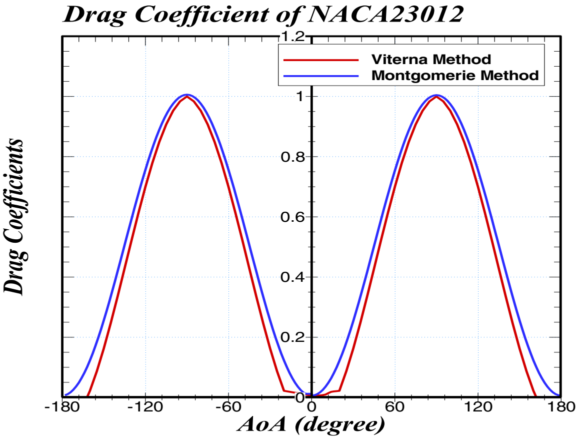


Fig. 4. Drag Coefficients of NACA23012 obtained from extrapolation with Viterna and Montgomerie Methods

From Fig. 4, it can be seen that there is a good agreement between the C_D curve computed with Viterna and Montgomerie methods. However, a relatively small difference in magnitude can also be noticed in the results. The difference depends on the parameters used in the computations.

From computation results shown in Figs. 3 and 4, it can be seen that both methods have a relatively good agreement and reliable to be used in computing three-dimensional (3D) performance of a wind turbine using the blade element momentum (BEM) method.

5. Conclusion

The present study extrapolate the limited lift and drag coefficients of NACA23012 using 2 (two) methods which are Viterna and Montgomerie methods. Both methods formulas and procedures are presented and demonstrated. A relatively good agreement of the airfoil performance in terms of lift and drag coefficients can be found from computation results which implies that both method are reliable to be used in three-dimensional computation of turbine blade performance.

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Biography

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