IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 09, Issue 1, January 2019, ||V-4|| PP 19-24

Upgraded Energetic Stall Prediction of Air Cylinder Airfoil

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ABSTRACT: *A dynamic stall model to predict the unsteady airloads on wind turbine airfoils where presents in this paper.The proposed model which is based on the Beddoes-Leishman (B-L) model and wind turbine applications are modified.S809 airfoil oscillating of the lift, drag and pitch moment in stall-development and deep-stall regimes are predicted. Overall good agreement for validation against available experimental data.*
KEYWORDS- *wind turbine; aeronyamics; airfoil; dynamic stall*

I. INTRODUCTION

Wind turbines operate in highly a high range of unsteady flow conditions. The dynamic stall due to dynamic variations of the Angle of Attack (AOA) of airfoils are customarily produce a large unsteady aerodynamic loads. Wind turbulence, yaw, pitch and rotational speed regulations lead to dynamic stall phenomena. The connected unsteady airloads are generally calculated by using a dynamic stall model [1,2].

Dynamic stall models studied for long years and some semi-empirical models are developed, such as the Boeing-Vertol model [3], the Beddoes-Leishman (B-L) model [4, 5], the ONERA model[6] and the Øye model [7]. In recent years, CFD techniques have also been used study the aerodynamics of airfoils[8 ,9]. But,except relatively simple cases,the solutions of CFD to be continue expensive and it is cannot used in routine engineering analyses of wind turbines.

In order to predict the unsteady aerodynamic loads on wind turbine airfoils, the model of dynamic stall is presented in this paper. The model is based on the B-L model and it adapted in operating conditions of wind turbine. The performance of the model is validated against measurements of the S809 airfoil.

II. METHODOLOGY

The B-L model are developed for helicopter applications, features such as attached flow, separated flow at the leading edge, trailing edge, and dynamic vortex [5].the model applied low Mach number flows [4] which arise in rotor of wind turbine. the thick airfoils (thickness≥15%) is used. In this airfoils, the leading edge separation is a rare and its effects is neglected. The model in this paper utilises the elements are used to calculate the unsteadyairloads:

1) the indicial response is the functions of modelling the unsteady attachedflow
2) the time-lagged Kirchhoff formulation is used to modelling thetrailing edge separation and dynamic vortex effects.

1.Attached flow

The 'attached flow' react in the B-L model and it is received by a superposition of indicial aerodynamic responses [5]. Under neath attached flow conditions, the superposition of a circulatory component C_N^C and a non-circulatory component C_N^I is obtained by the normal force co-efficient.

$$C_N^p = C_N^C + C_N^I \qquad (1)$$

The tangential force coefficient using the effective AOA α_E:

$$C_C^p = C_N^p \tan\alpha_E \qquad (2)$$

Similarly, the normal force coefficient and the pitching moment can be given as:

$$C_M^p = C_M^C + C_M^I \qquad (3)$$

2. Trailing edge separation

The results of the flow separation is loss of circulation about the airfoil, the attached flow values are reducing aerodynamic forces. The separation point is given by $f = x/c$, where x is the distance to the point of flow separation measured by the leading edge, and c is chord length. The Kirchhoff flow equation to find the relationship between the normal force and fixed separation point. Let us consider the high AOA the wind turbine airfoils may frequently operate at, the equation can be changed as[4]:

$$C_N = C_{N\alpha}\sin(\alpha - \alpha_0)\left(\frac{1+\sqrt{f}}{2}\right)^2 \quad (4)$$

where $C_{N\alpha}$ is the slope of the normal force coefficient curve, α the AOA, and α_0 the zero-lift angle of attack. Similarly, the tangential force coefficient can be corrected as:

$$C_C = C_{N\alpha}\sin^2(\alpha - \alpha_0)\sqrt{f} \quad (5)$$

First measured the value of C_N and α, then to find the relationship between the effective separation point and AOA by solving for f terms of using Eq. (4). Below the dynamic conditions, the change of the effective AOA and the delay of boundary layer separation due to the separation point will be delayed. After assume the unsteady attached flow, the effective AOA may be given as:

$$\alpha' = C_N^p / C_{N\alpha} + \alpha_0 \quad (6)$$

The effective AOA α' can be used to obtain the effective separation point f'. The additional effects due to the delayed boundary layer separation are considered by introducing the first-order lag it used to observe the dynamic separation point f'':

$$\frac{df''}{ds} = \frac{f' - f''}{T_f} \quad (7)$$

where T_f is a time constant, and s is a nondimensional time ($s = 2Vt/c$, where V is the freestream velocity, and t the time). Using f'', the force coefficient is consideration as trailing edge separation it can be obtained by using Eqs. (4) and (5).

The success of the above method depends on an accurate solution of the static airfoil characteristics, including static force coefficients and separation point. These parameters form the basis subtract the required dynamic forces. In the original B-L model to calculate the C_N, C_c by using separation point and also to found the range AOA by using Eqs(4),cannot reproduce correct values of C_C using Eq. (5). In this study, the separation point curves for C_N and C_C are calculated separately as f_N and f_C. Fig. 1 shows the two separation point curves for S809. Clearly, when the AOA is greater than6° the discrepancy between two curves.

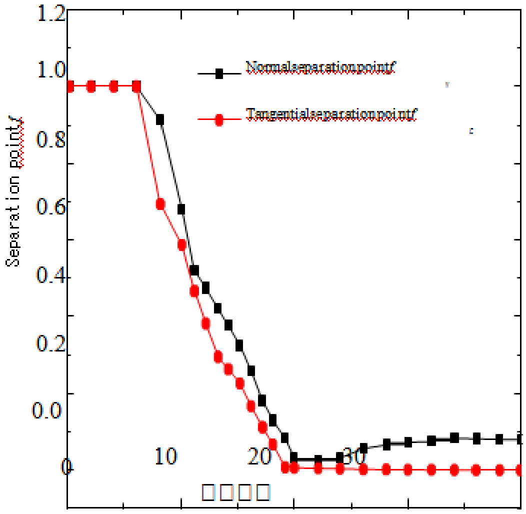

Fig. 1. Static separation point

For fully separated flow, the tangential force coefficient value is negative. the square root of f in Eq. (5) is also negative and it regenerate the value of aerodynamic coefficient. But the negative sign is lost in Eq. (5) and it cause problems in reproducing C_C. In the B-L model, a negative C_C not be represntedcorrectly . To eliminate this problem [10], the sign is saved with the value of the tangential separation ofpoint $f_C$as:

$$f_C = F^2 \text{sign}(F) \tag{8}$$

where

$$F = \frac{C_C}{C_{N\alpha} \sin^2(\alpha - \alpha_0)}$$

Eq. (5) is then revised as:

$$C_C = C_{N\alpha} \sin^2(\alpha - \alpha_0) \sqrt{|f_C|} \text{sign}(F) \tag{9}$$

From the Eq. (4) and Eq. (9) the calculation of dynamic separation point f_N" and f_C", the non-linear force coefficients C_N^f and C_C^f can be obtained respectively.

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An empirical relation was proposed in the original B-L model [5]. the pitching moment co-efficient. However to determined by curve fitting is the parameters formula are different for each airfoils. To provide a generalised solution, the method proposed by Minnema [11] is employed. A 'look-up' table correlating the AOA with the moment coefficient is used. Similar to Eq. (7), a first-order lag is introduced to obtain the dynamic AOA□":

$$\frac{d\alpha''}{ds} = \frac{\alpha' - \alpha''}{T_\alpha} \tag{10}$$

where T_α is a time constant. Using □", the non-linear moment coefficient C_M^f can be obtained via the look-up table.

Dynamicvortex

During the dynamic stall, the airloads will affect due to vortex build-up and shedding near the leading edge of the airfoil. In the B-L model, the lift increase it is defined the difference between the unsteady circulatory lift and the unsteady lift is given by modified Kirchhoff equation [5]. The cumulative vortex lift is allowed to decay fraction time, but may also be uploading a new lift increment to get the total vortex-induced normal force coefficient CN^V. An T_V is an empirical time constant is introduced to describe the destroy the vortex. The formation and shedding of vortices also participates to the pitching moment. C^v is the vortex induced pitching moment co-efficient when it is defined by considering the aft movement of the centre of pressure [5], the introduced a vortex traversal time constant T_{vl}.

When the effects of the dynamic vortex in the tangential force were not investigated in the original B-L model. Whenever, the studies of unsteady data showed the vortex component it also contributes to the tangential force. In our proposed model, the equation suggestion by Pierce [10] is adopted to obtain the vortex-induced tangential force coefficient:

$$C^v \square\ C^v \square\square'(1 \square \square\ ) \qquad (11)$$

Where $\square_v$ is the non-dimensional vortex time ($\square_v = 0$ at the onset of separation conditions and $\square_v = T_{vl}$ when the vortex reaches the trailing edge).

At last, the total unsteady loading on the airfoil can be obtained as:

$$C_N \square C^I_N \square C^f_N \square C^v_N$$
$$C_C \square C^f_C \square C^v_C \qquad (12)$$
$$C_M \square C^C_M \square C^I_M \square C^f_M \square C^v_M$$

The lift and drag coefficients are then given as:

$$C_L \square C_N \cos\square \square C_C \sin\square \qquad (13)$$
$$C_D \square C_N \sin\square \square C_C \cos\square \square C_{D0}$$

where C_{D0} is the zero-lift drag coefficient.

III. RESULT ANDDISCUSSION

Fig. 2 shows the reproduction of static aerodynamic force coefficients for S809 airfoil using Eq. (4) and Eq. (9). Excellent agreement is observed in the entire region of the AOA. The negative value of C_C in the deep-stall regime is correctly reflected, which would not be produced by the original B-Lmodel.

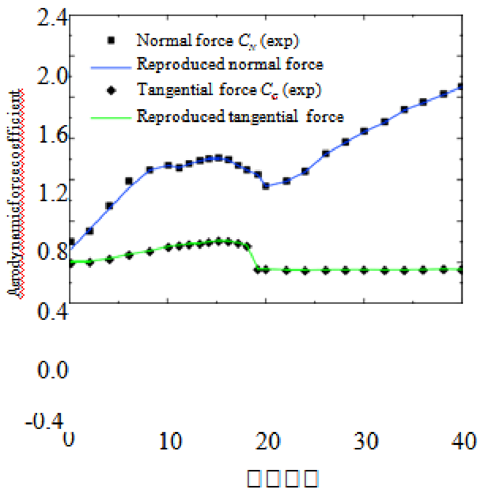

Fig. 2. Reproduced S809 static aerodynamic force coefficients using static separation point

Using the proposed model, the S809 airfoil undergoing pitching motion of aerodynamic forces were simulated. The airfoil is set to pitch harmonically, i.e., $\alpha = \alpha_m + \Delta\alpha \sin \omega t$, where α_m is the mean AOA, $\omega = 2Vk/c$ and k is the reduced frequency. the model for both airfoils are set as [4] by using empirical: $T_f = 3.0$, $T_\alpha = 0.3$, $T_V = 6.0$ and $T_{Vl} = 11.0$. Experimental results of wind tunnel tests [12] are used for the validation.

Fig. 3 and Fig. 4 show the predicted C_L, C_D and C_M for S809 airfoil in the stall-development and deep-stall regimes, with mean AOA of 14° and 20° respectively. The dynamic aerodynamic loads are predicted well by the model. The modified model is superior to the original model in the prediction of almost all of the force coefficients. To estimated better maximum and minimum values by the modified model, especially for C_D. The hysteresis loops predicted by the modified model show much smaller deviations from the measurements than those predicted by the originalmodel.

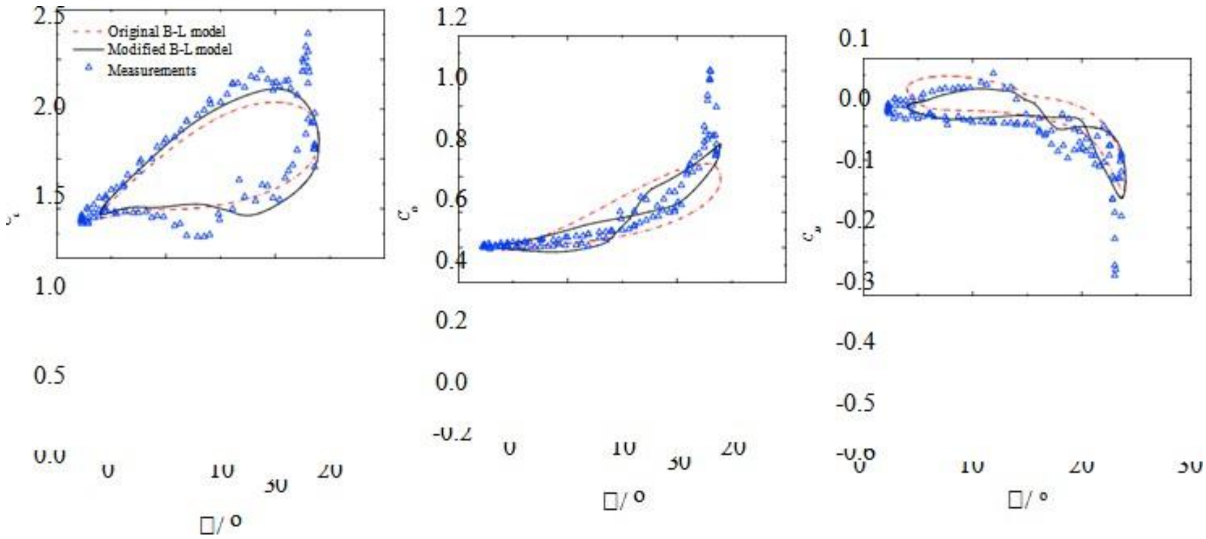

Fig. 3. S809 aerodynamic force coefficients vs AOA, $\alpha = 14 + 10\sin(\omega t)$, $k = 0.1$

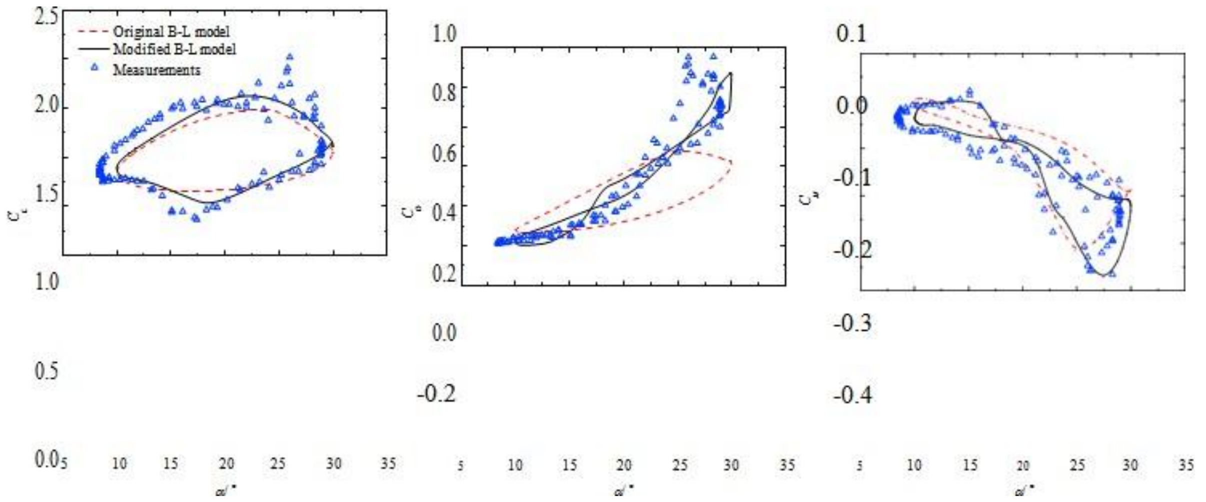

Fig. 4. S809 aerodynamic force coefficients vs AOA, $\alpha = 20 + 10\sin(\omega t)$, $k = 0.078$

Also the proposed model has also been applied to other wind turbine airfoils and shown the improvement over the original model. It is also indicates that the proposed model is suitable to different wind turbine airfoils.

IV. CONCLUSION

In this study, to estimate the unsteady aerodynamic loads on wind turbine blades due to dynamic stall by the modified B-L models validated through modelling the pitch oscillations of the S809 airfoil to the proposed model. The modified model improve over the original model. The capabilities of the model also include:

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correct prediction of negative values of the tangential force coefficient in deep-stall regime;
ageneralisedformulationforthepitchingmomentcoefficientassociatedwithtrailingedgeflowseparation;and
the consideration of the vortex-inducedtangentialforce.

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