Theoretical performances of double Gurney Flap equipped the VAWTs

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Abstract: *A Gurney flap is simply a flat plate attached perpendicularly to the lower surface of an airfoil or wing trailing edge. A T-strip or double Gurney flap is attached to both the upper and lower surfaces. T-strips are used to modify the lifting characteristics of the baseline airfoil for vertical axis wind rotor turbines. Generally, T-strips have been used during developmental flight test as simple add-on "fixes" to improve the performances of existing aircraft vertical tails. This paper aims to investigate the performances of VAWTs equipped with T-strip on blades trailing edge.*

Key Words: *Gurney Flap, VAWT, CFD, T-strip*

1. INTRODUCTION

In this study we use some devices on a trailing edge of a standard airfoil NACA 0012 trying to increase the lift coefficient. A Gurney flap [1] is simply a flat plate attached perpendicularly to the lower surface of an airfoil and in this case we also used in the airfoil upper surface. This trailing edge device is illustrated below in Figure 1. Liebeck's [2] results showed a significant increment in lift as compared to the baseline airfoil. In general, the drag of the airfoil increases with the addition of the Gurney flap, but often the percentage increase in lift is greater, resulting in an increased lift-to-drag ratio and therefor a better efficiency and performance.

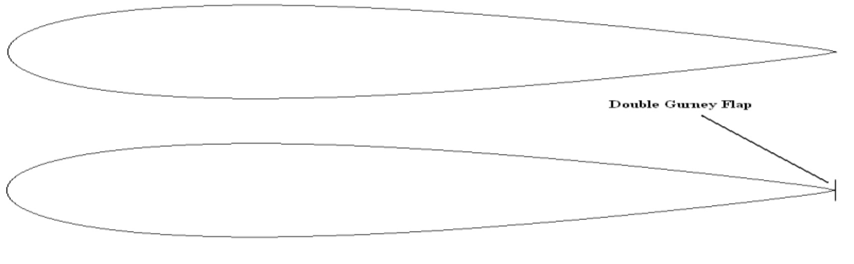


Figure 1. Airfoil with and without Gurney Flap

Normally, a device like Gurney Flap is used for increase the lift coefficient of airfoils. Typical applications studied have been made on wind turbine blades. By using the double Gurney Flap the study became similar with a study where was used the T-strip device. T-strips have been used to improve the performance of aircraft vertical tails [3].

Despite being used on a number of aircraft vertical tails, very little studies exist in the literature on the effect of trailing edge T-strips. In this study we used this double Gurney Flap on an airfoil for vertical axis wind turbine.

The Darrieus turbine is the most common VAWT invented in 1931[4]. The biggest turbine that was built had a rated power of 4 MW [5].

In the 70s, Peter Musgrove [6] studied this concept and with some help from several researchers they developed the straight-bladed Darrieus turbine, also called H-Darrieus. In the electricity generation market the HAWT type has currently a large predominance.

The maximum power which can be extracted from a wind turbine in open flow can be calculated with the Betz law [7].

According to Betz's law, no turbine can capture more than 16/27 (0.593- Betz's coefficient) of the kinetic energy in wind.

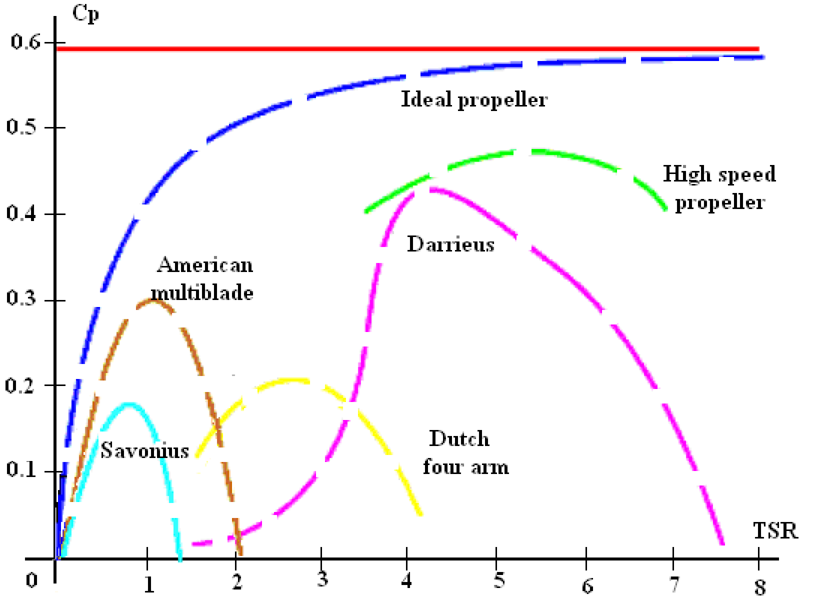


Figure 2. Cp-TSR diagram for different type of wing turbine

To determine the influence of the double Gurney Flap on the wind turbine performances we define, with an CFD analise, the polar diagram which we will used in an in-house code to determine the power of this turbine.

2. SIMULATION METHOD

Computational fluid dynamics (CFD) is a useful design tool for wind power analysis. Using CFD simulations, the lift and drag coefficients of the wind turbine airfoil can be predicted. The simulation was performed in a 2-D space domain with a commercial CFD code - ANSYS Fluent[8].

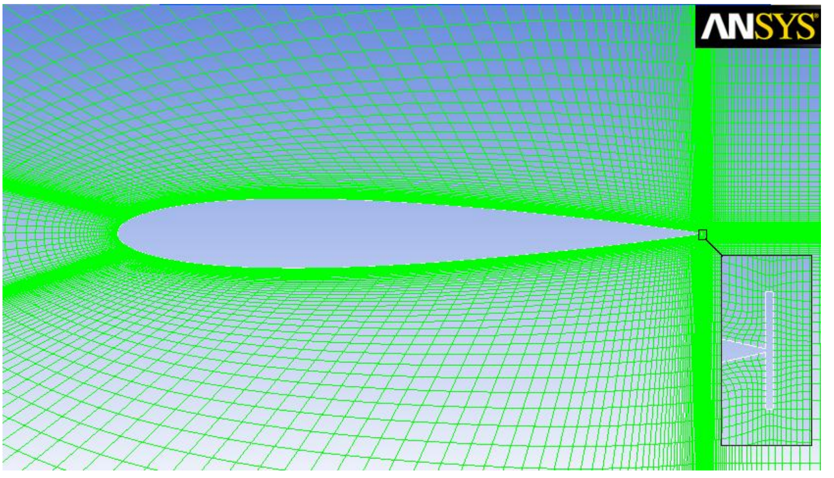


Figure 3. Mesh discretization

The choice of the turbulence models influences the resultant flow field and the computational resource and time required to achieve solutions. For this analyze we use the standard k–ω model to achieve accurate results. The equations (1),(2) of this model are coupled to the Navier-Stokes equations system to define the flow around the airfoil:

- k equation:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial}{\partial x_j}(\rho U_j k)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+P_k-\beta'\rho k\omega+P_{kb} \quad (1)$$

- ω equation:

$$\frac{\partial(\rho\omega)}{\partial t}+\frac{\partial}{\partial x_j}(\rho U_j\omega)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\omega}\right)\frac{\partial\omega}{\partial x_j}\right]+a\frac{\omega}{k}P_k-\beta\rho k\omega^2+P_{\omega b} \quad (2)$$

The effect of Gurney flaps on the baseline airfoil lift curve is shown below in Figure 4. The coefficient data presented in Figures 4 was taken at a Reynolds number of $4x10^4$. The coefficient data show that Gurney flaps produced a positive increment in lift coefficient.

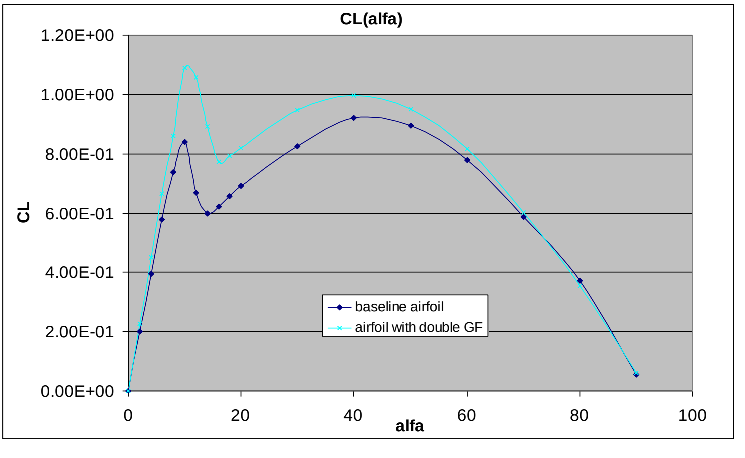


Figure 4. Polar diagram

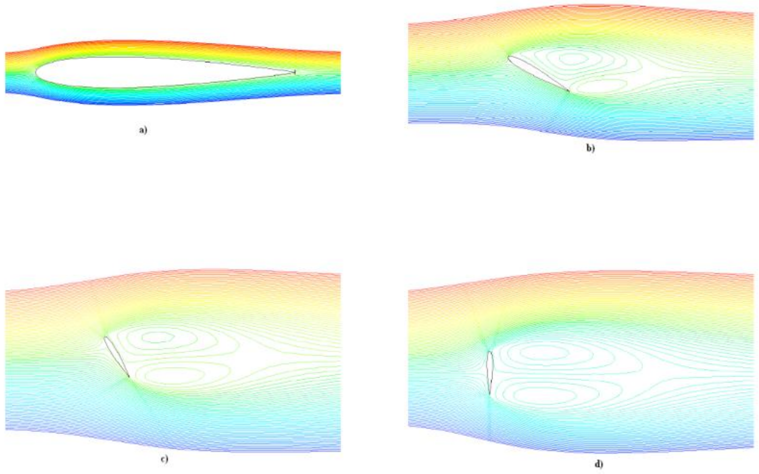


Figure 5. Streamlines at different incidence angles:
a) 0 grd, b) 30 grd, c) 60 grd, d) 90 grd

3. THEORETICAL SIMULATION

Vortex Model. The local air velocity relative to a rotor blade consists of the free stream velocity due to the blade motion and the wake induced velocity. In order to predict the inflow at the blades it is necessary to describe the blade surface and the wake. The blades are simply lifting surface of large span, so each blade of the rotor is represented by a bound vortex lifting line located along the rotor blade quarter chord line with the incident-flow boundary condition met at the three quarter chord location.

The wake consists of shedding span wise vortex filaments resulted from the temporal variation in loading distributions on the blades as required by Kelvin’s theorem.

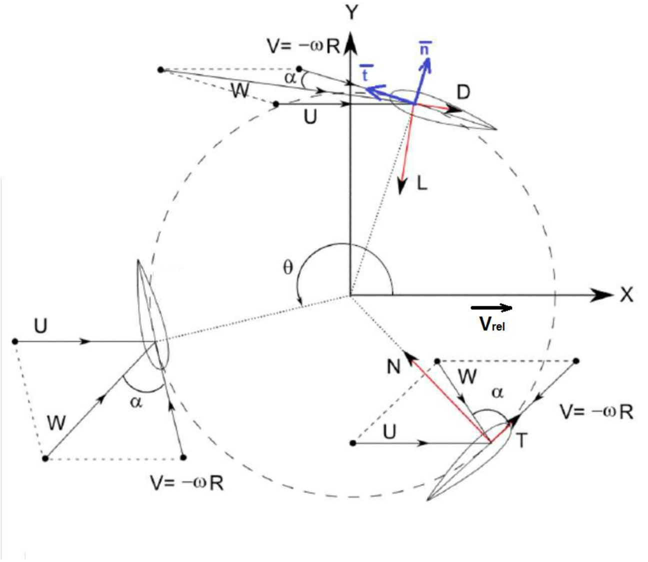


Figure. 6 Two-dimensional rotor configurations

Referring to Fig.6, the following relationships can be obtained:

$$\vec{V}_{rel} = (V_\infty + u + U_T \cos\theta)\vec{i} + (w - U_T \sin\theta)\vec{k} \tag{3}$$

$$\alpha = \tan^{-1} \frac{\vec{V}_{rel}\vec{n}}{\vec{V}_{rel}\vec{t}} \tag{4}$$

Unlike the vortex methods developed in the past based on steady airfoil data for the lift *(C_L)* and drag *(C_D)* coefficients, the present method utilizes the BoeingVertol empirical model to approximate the dynamic-stall characteristics.

The blade airfoil section tangential and normal force coefficients C_T and C_N can be written as:

$$\begin{aligned} C_T &= C_L \sin\alpha - C_D \cos\alpha \\ C_N &= -C_L \cos\alpha - C_D \sin\alpha \end{aligned} \tag{5}$$

where the section lift and drag coefficient C_T and C_N are also yielded by the dynamic stall model.

The instantaneous blade loadings are defined in terms of the non-dimensional normal and tangential forces as follows.

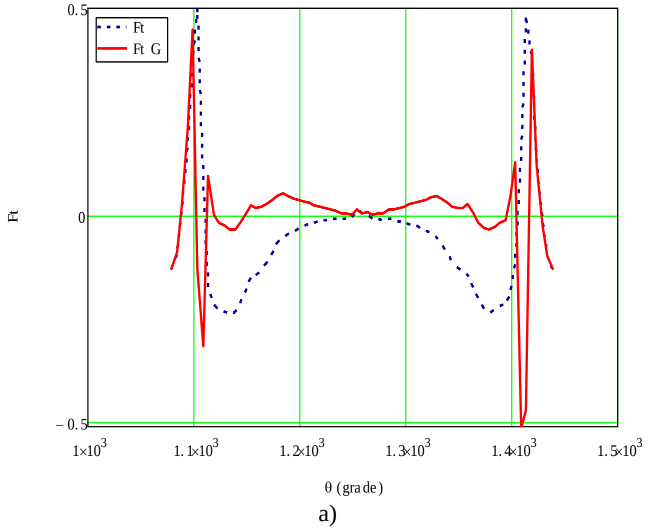
The average power coefficient for the entire rotor during a single revolution is given by:

$$C_p = \frac{TSR}{NTI}\frac{c}{2R}\sum_{j=1}^{NTI}\sum_{i=1}^{NB} C_{Tij}\left(\frac{V_{rel}}{V_\infty}\right)_{ij}^2 \tag{6}$$

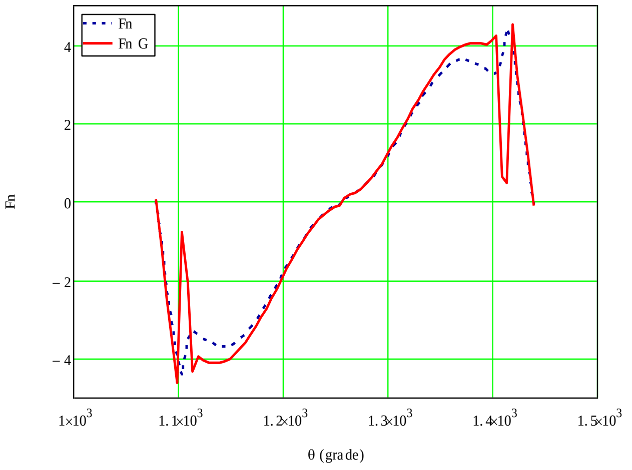
Where *NTI* is the number of the time steps per revolution of the rotor.

4. RESULTS

As results we represent below the variation of Ft and Fn depending on the position of the blade (figure 7).



a)



b)

Figure 7. The force in a VAWT: a) tangential force, b) normal force

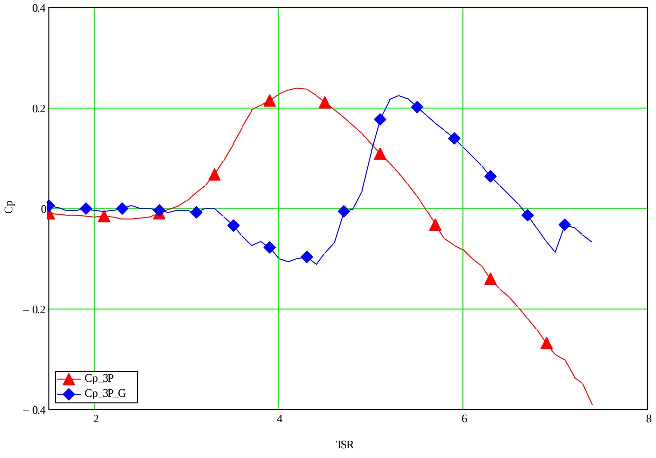


Figure 8. Power coefficient

5. CONCLUSION

1. Based on the theoretical simulation, a computer program has been developed to predict the force and moments of a vertical axis wind turbine (VAWT).
2. The double Gurney Flap has a good influence in the wind turbine power when the tip speed ratio is high.
3. At small tip speed ratio, the double Gurney Flap influence is bad because the dynamic stall is more present.

6. REFERENCES

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