*Proceedings of the 8th Academic Sessions, University of Ruhuna 2010*
*Vol. 8 pgs 56 – 62*

**BF - 01**

# Study on vertical axis wind turbine with introducing new turbine blade profile and deflector-rudder unit

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## Abstract

At present, Sri Lankan government has paid more attention to generate electricity from the renewable energy sources. As a result of that wind energy has been identified as one of the promising candidate to generate electricity in the future. Therefore performance improvement of the wind turbine under the wind condition in Sri Lanka should be addressed. The objective of this study is to improve the performance of Straight Vertical Axis Wind Turbine (S-VAWT) by introducing new turbine blade profile and deflector-rudder unit. The wind turbine blade has been designed considering effect of lift and drag forcers acting on the blades which were obtained by the results of CFD simulation. Shapes and positions of the deflectors were selected as maximize the torque effect to the turbine on the relevant region. CFD simulation has been used to compare the performances of a turbine with new blade profile with that of NASA profile. The results show that, new blade profile with deflector-Rudder unit has better power extraction ability than existing designs due to effective projection of the wind toward the blades by deflectors.

## Introduction

At present, electricity requirement in the Sri Lanka is mainly obtained from hydro-power plants and thermal power plants operated by fossil fuel. All most all hydropower potentials has been recently identified and used for the purpose of power generation. To fulfill the increasing demand of the country, present government has chosen thermal power as their second option to generate electricity. According to the present energy scenario in Sri Lanka, 65% of electricity is generated by fossil fuel (Young and Vilhauer, 2003). However, due to the depletion of fossil fuel reserves in the world and increase of environmental issues, this source of energy is not promising candidate in the near future. Now trend in the world is to move towards the renewable energy sources as they are sustainable.

Recently, wind energy has been identified as one of the important energy option in Sri Lanka (Annonymous, 2000). National renewable energy laboratory estimates that the windy land represents about 6% of the total land area (65,600 km$^2$) of Sri Lanka (Young and Vilhauer, 2003). Using a conservative assumption of 5 MW per km$^2$, this windy land could support almost 24,000 MW of potential installed capacity (Narayana, 2009). Therefore it is worthwhile to develop a wind turbine which is more suitable for wind conditions in Sri Lanka.

The recent studies on S-VAWT shows that the maximum power coefficient of Darrieus –Savonius hybrid configuration could reach up to 0.231 when tip speed becomes 3.76 (Wakui, 2005).

In this study, Darrieus type wind turbine, which is classified as S-VAWT, is taken into consideration. This type turbine has many advantages as the mechanism of its power generation is not affected by the wind direction, and it can be connected a generator, a gear box and a controller in low position. The objective of this work is to design an S-VAWT with high power coefficient by introducing new turbine blade profile and deflector-rudder unit at low wind speeds. This design is most suitable to fulfill the energy requirements of domestic users. The present study is mainly conducted by using Computational Fluid Dynamic (CFD) software which may be more reliable than the analytical or semi-empirical models adopted with simplifying assumption (Cheng and Hu, 2008)

*Blade Profile*

In most of the past studies on VAWT, blade profiles or airfoil sections selected for turbine blades are standard profiles provided by NACA codes [6, 7, and 8]. In this study, new blade profile has been proposed in relation with introduction of the deflector-rudder unit (DRU) for maximization of power coefficient.

The blade profile is designed with four sections combine together as shown in the Figure 1. Expressions selected for four sections together with their variables are given in Table 1. The independent variables, a, b, c, d, e and f are evaluated by using trial and error method to maximize the power coefficient.

**Table 1: Expressions selected for four sections**

| Section | Relevant equation |
|---|---|
| Ellipse 1 | $x = b \cos(\theta)$<br>$y = a \sin(\theta)$ |
| Curve | $y = a_1x^4 + a_2x^3 + a_3x^2 + a$ |
| Straight line | $y = mx - c$ |
| Ellipse 2 | $x = b \cos(\beta)$<br>$y = c \sin(\beta)$ |

First Section is an ellipse 1 from (-b, 0) to (0, a). Equations $x = b \cos(\theta)$ and $y = a \sin(\theta)$ are used to find coordinates. $\theta$ varies from $\pi/2$ to $\pi$. In the section 2, a curve, $y = a_1x^4 + a_2x^3 + a_3x^2 + a$ is assumed from (0,a) to (d, e ). The section 3 is a straight line from (d, e) to (0, c). Section 4 is also an ellipse. Coordinates of the this section can be determined by the equations $x = b \cos(\beta)$ and $y = c \sin(\beta)$. Angle $\beta$ in the expression varies from $\pi$ to $3\pi/2$.

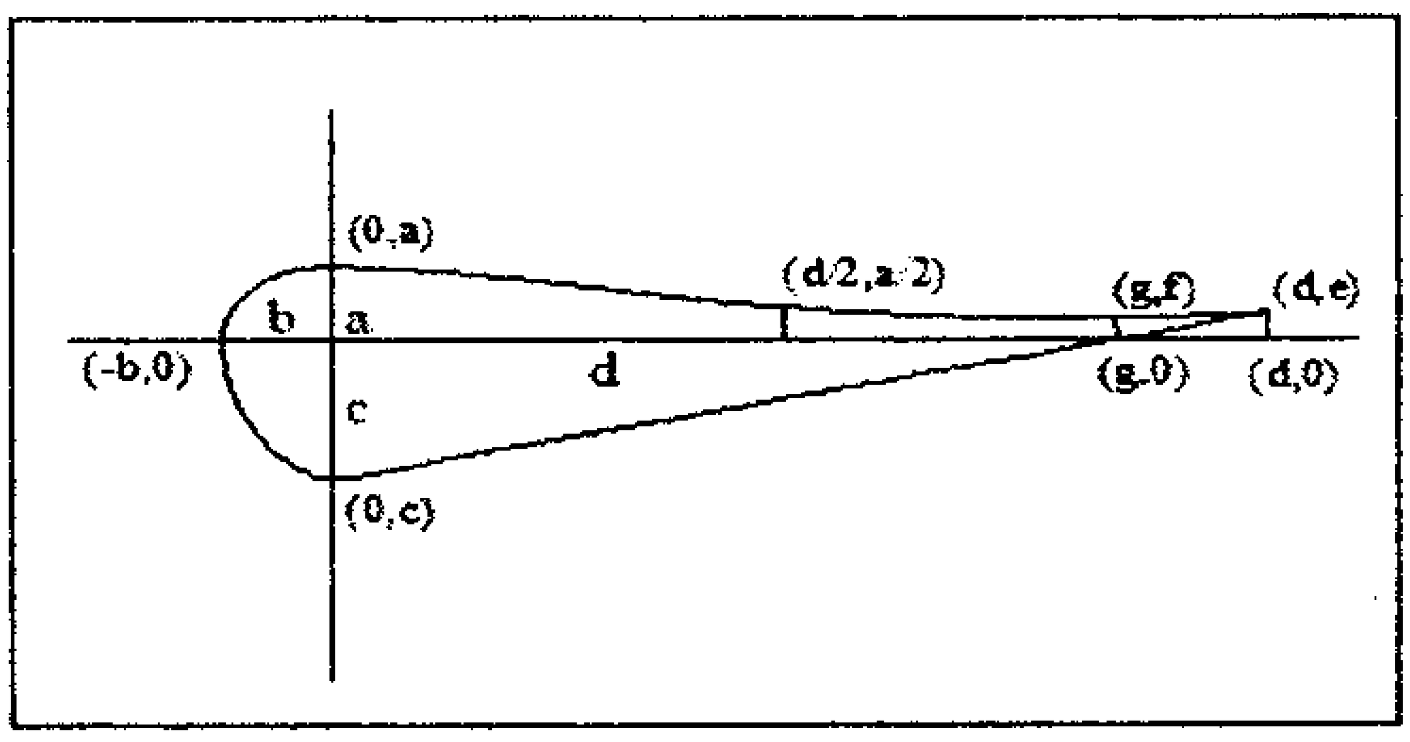



**Figure 1: Four sections of the blade profile in x-y coordinate system**

Base point of x-y coordinate system is converted to the X-Y coordinate system of which origin is at the center of the turbine as shown in the figure 2(a). In the conversion, Relationship between x-y coordinate and the X-Y coordinate is considered as follows.

$X = (r+ y)^* \sin(x/r)$ -------------------- (1)

$Y = (r + y)^* \cos(x/r)$ ------------------- (2)

Where,

r- Radius of the turbine.

After conducting series of simulations for wind speed range from 4m/s to 12m/s, have been found most suitable values for the independent variables.

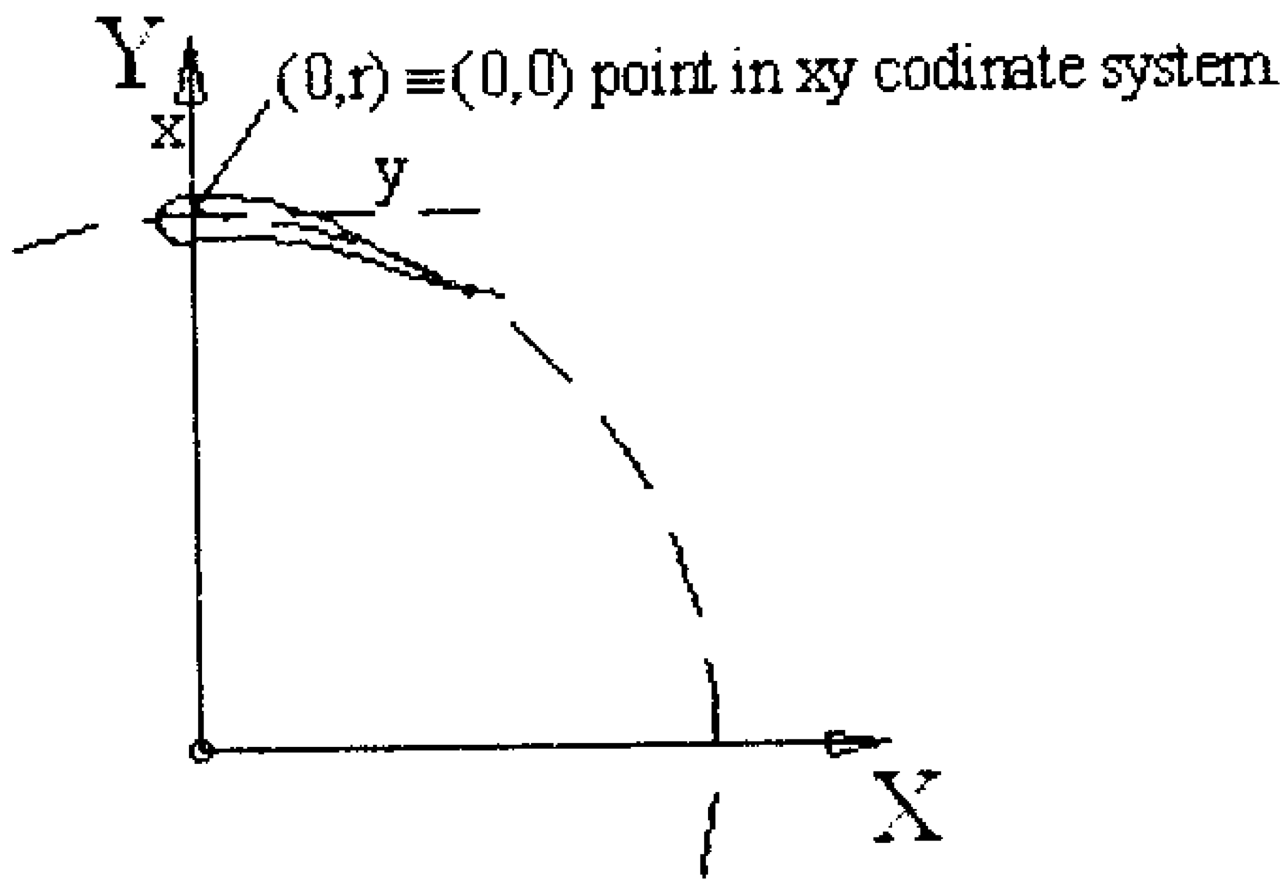



**Figure 2(a): Coordinate system with reference to center of the turbine**

The typical shape of the blade profile proposed by this study as shown in figure 2(b).

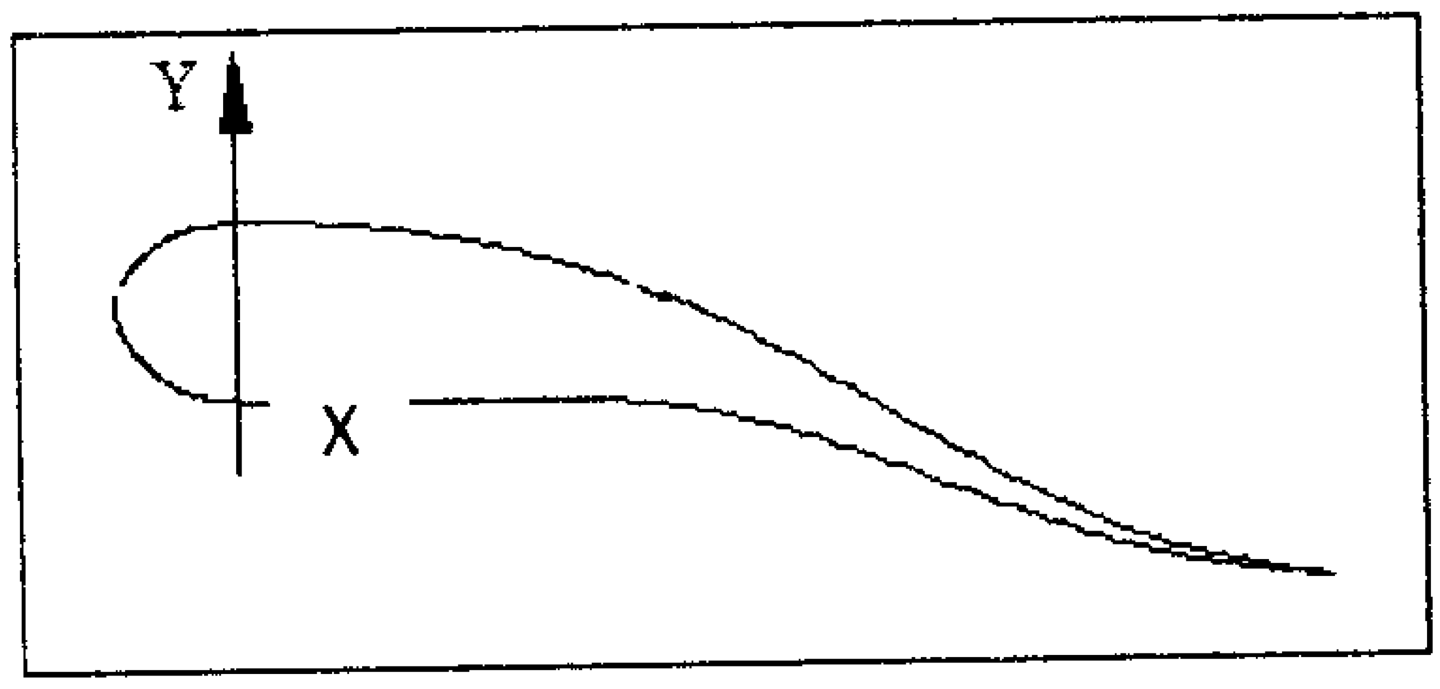



**Figure 2(b): A typical profile shape of the blade**

*Deflector-Rudder Unit (DRU)*

Deflector-Rudder unit consist of three different deflectors and a Rudder (York). The DRU is mounted on a pipe which is connected with the support of two bearings on housing of the main shaft as shown in the Figure 3. Therefore the turbine shaft can rotate freely and there is no resistant torque on the turbine shaft due to the DRU. Deflectors are introduced to the turbine for effective projection of upstream wind into the rotating blades.

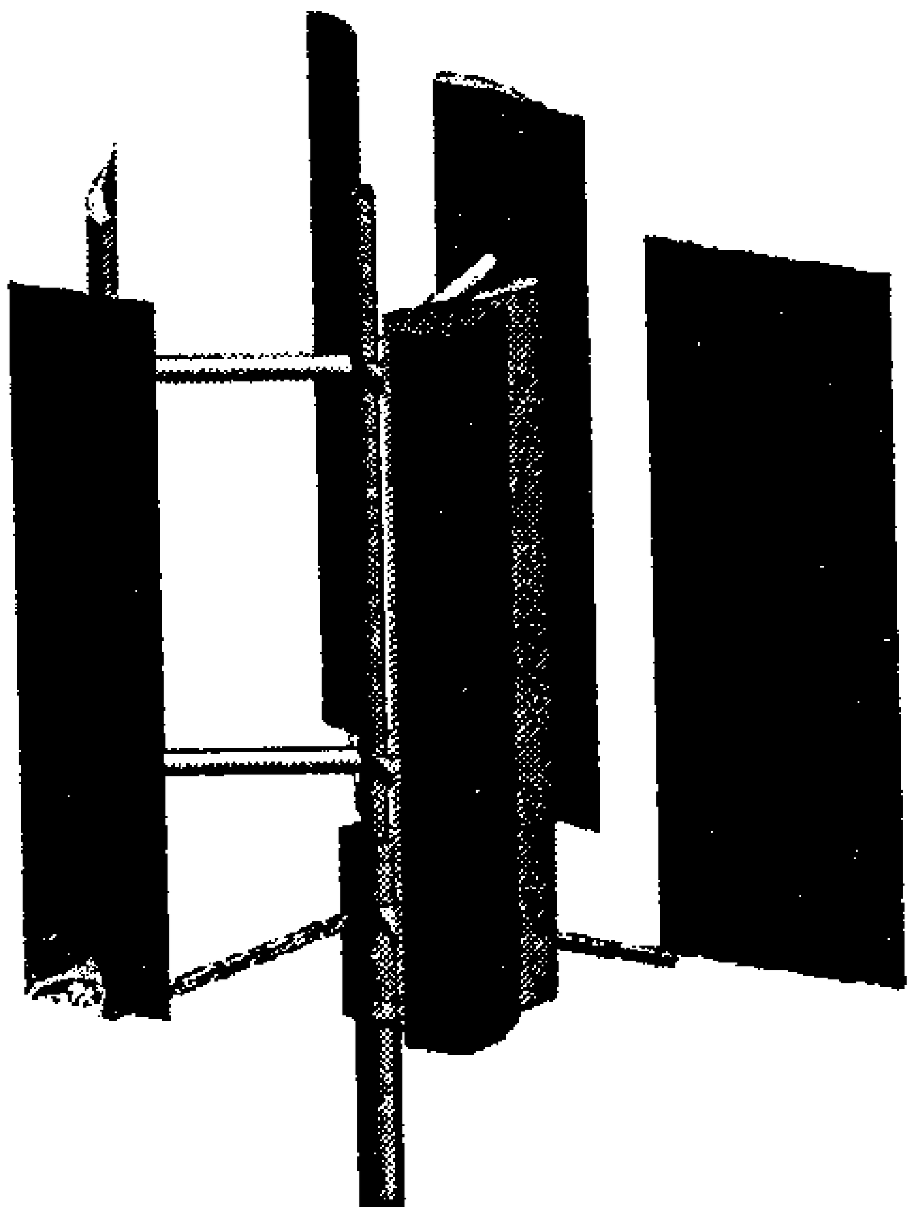


**Figure 3: Turbine with deflector-rudder unit**

In order to obtain the suitable positions of the deflectors, first CFD simulations were conducted for the turbine with new blade profile without DRU and positions of the minimum torque on the shaft were found, and then to find the exact position and shape of the deflector CFD simulations are conducted several times by changing a position or shape of one deflector while keeping other two deflectors at fixed, until positive torque on the shaft appears at most of the angular positions. The positions and shape of the three different deflectors are obtained relative to the rudder are shown in Figure 4.

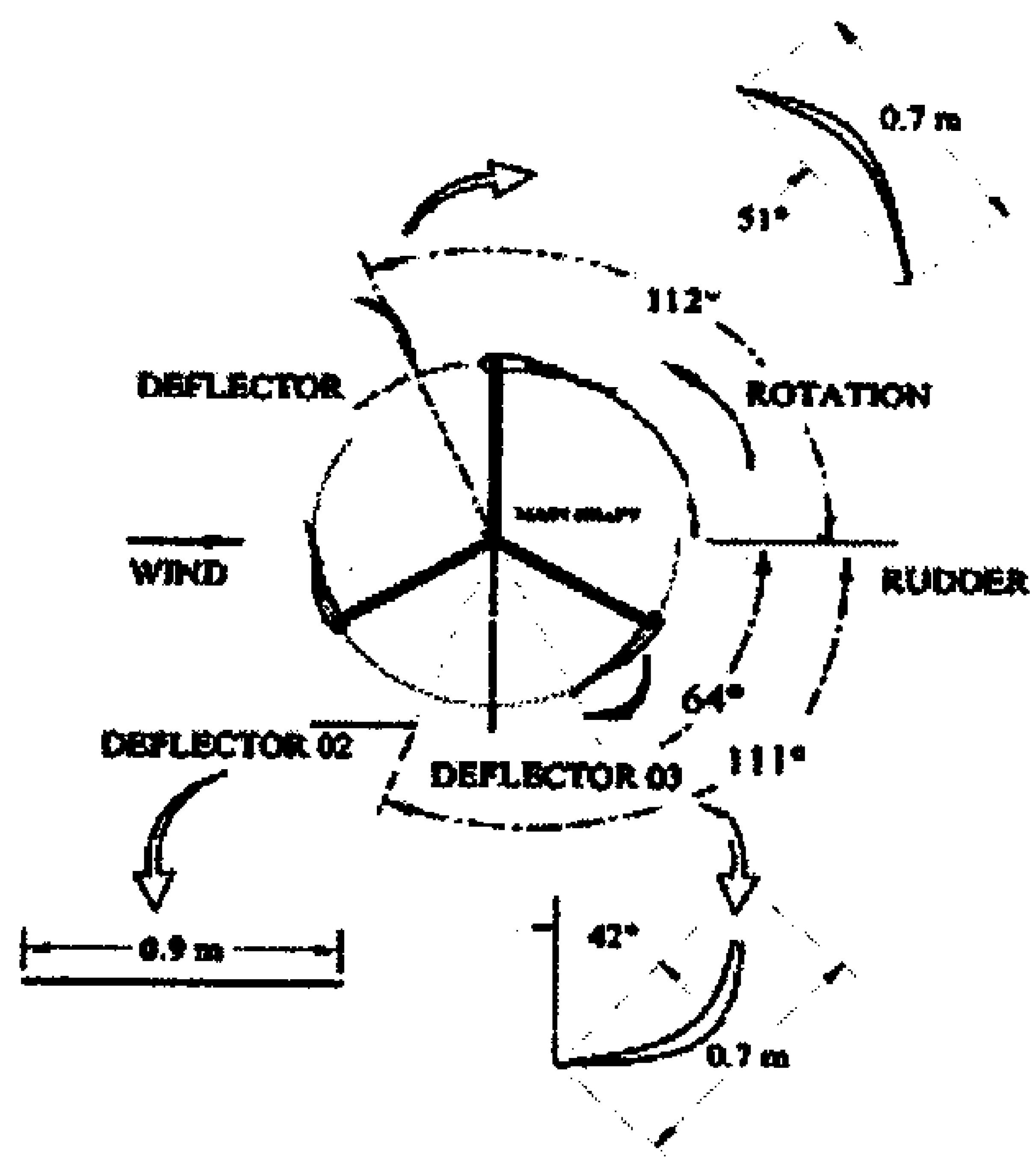



**Figure 4: The plan view of the blades with DRU**

*Verification of simulation results*

In order to confirm the correctness of the simulation technique and results obtained from the present study, experimental results obtained by Takao *et al.*, (2009) for a Straight Vertical Axis Wind Turbine (S-VAWT) are duplicated by using the present simulation techniques. Takao et al observed experimental power coefficient for rotor blade profile of NACA 4518 as shown in Figure 5.

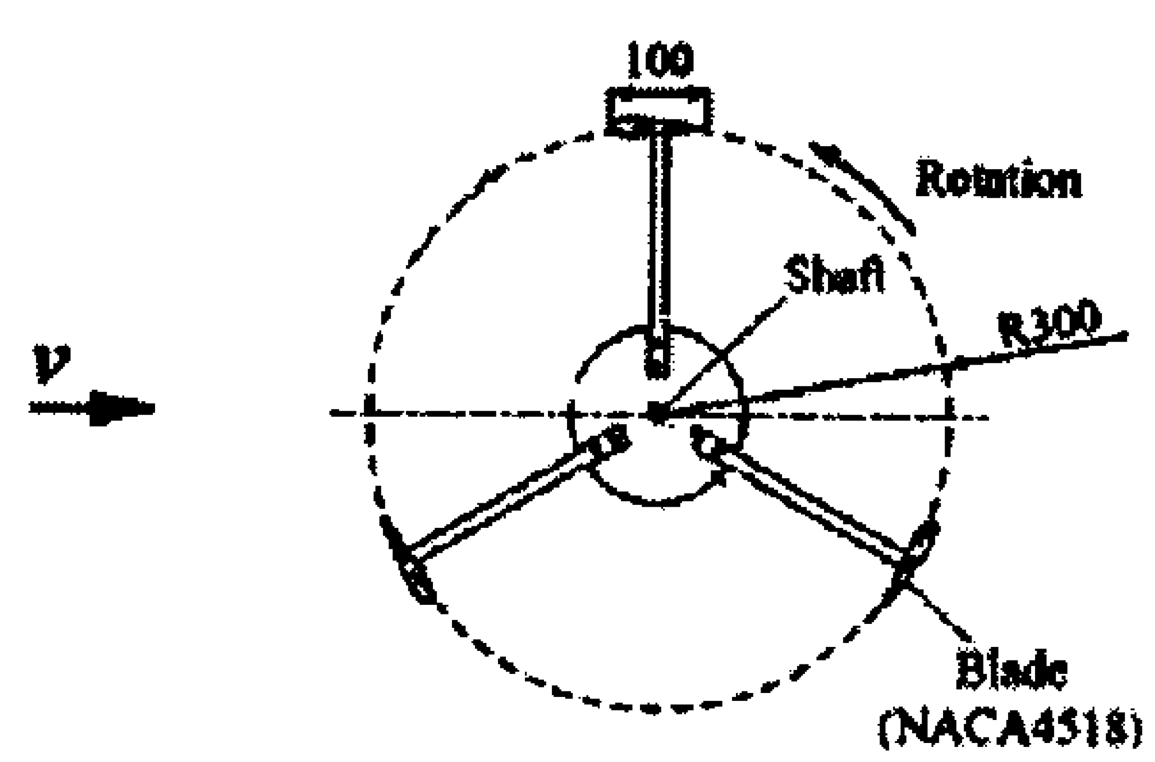



**Figure 5: Straight-bladed vertical axial wind turbine**

Figure 6 shows variation of power coefficient Cp, with tip speed ratio λ, observed by their experiments and that duplicated by the present study using Computational Fluid Dynamic [CFD] results. Our simulation results show good agreement with the experimental results. Therefore it is instructive to use present simulation method for further study of VAWT under similar operating conditions.

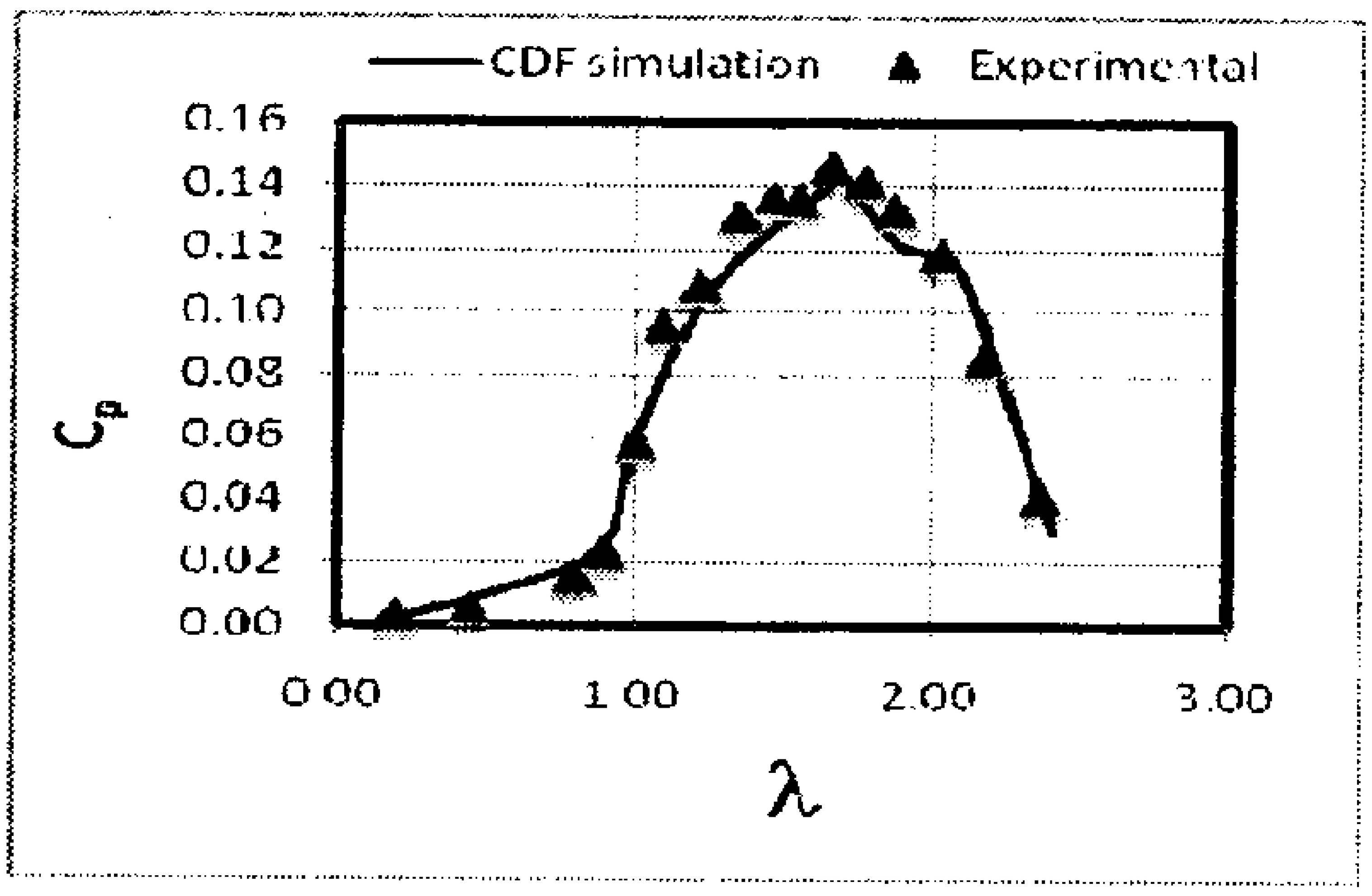
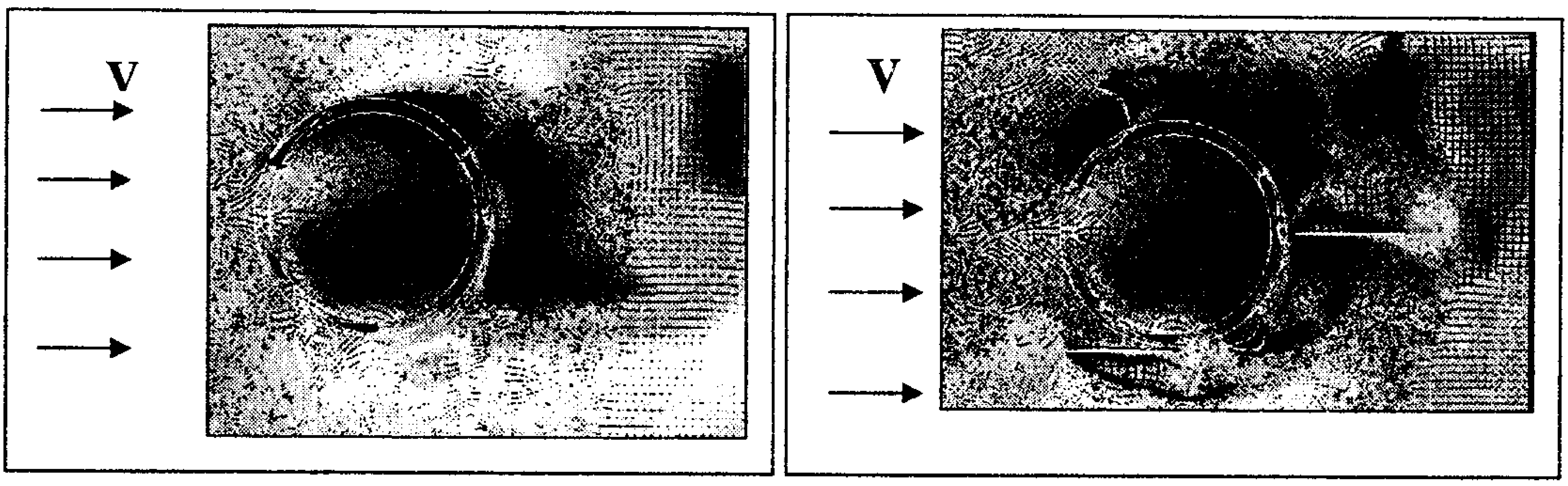



**Figure 6: Comparison of experimental results of Takao *et al.* with the present simulation results**

## Simulation Result

Figure 7 shows Instantaneous wind speed variation around the wind turbine with and without DRU. The dark areas indicate low wind speed areas and contrary white spaces show us high wind speed areas.




**(a)Without deflector-rudder unit** **(b) With deflector-rudder unit**

**Figure 7: Velocity variation around the wind turbine**

When comparing Figure 7 (a) and (b) it is found that upstream wind speed remarkably reduce when the wind flow through the turbine in the case of the turbine having a DRU in Figure 7 (b). This might be due to the fact that more kinetic energy is absorbed by the turbine.

*Performance of the Turbine*

The performance of the turbine can be expressed in terms of Power Coefficient (Cp) with respect to tip-speed ratio (λ). In this analysis, the following relations are used,

Co – efficient of performence $Cp$

$$Cp = \frac{P}{0.5\rho V^3 A}$$

$$\text{Tip speed ratio} = \frac{\text{Velocity of blade tip}}{\text{free steam velocity}}$$

Where *A*: swept area [m2]; $C_P$: power coefficient; *P*: output power [W]; *V*: inflow wind speed [m/s]; ρ: air density [kg/m3].

Power coefficient values obtained for new blade profile, new blade profile with DRU and NACA 0015 blade profile with DRU using CFD simulations under the following wind conditions and rotor dimensions of the turbine.

| | |
|---|---|
| Code length of rotor blade | 1 m |
| Rotor diameter | 3 m |
| Rotational speed of rotor | 75 rpm |
| Number of blade | 3 |
| Wind velocity range | 4-12 m/s |
| Swept volume | 9 m$^2$ |

Figure 8 shows, for all tip speed ratios, the power coefficient is much greater for new blade profile with DRU. Furthermore at tip speed ratio of 1.25, the new blade with DRU has maximum power coefficient of nearly 0.3.

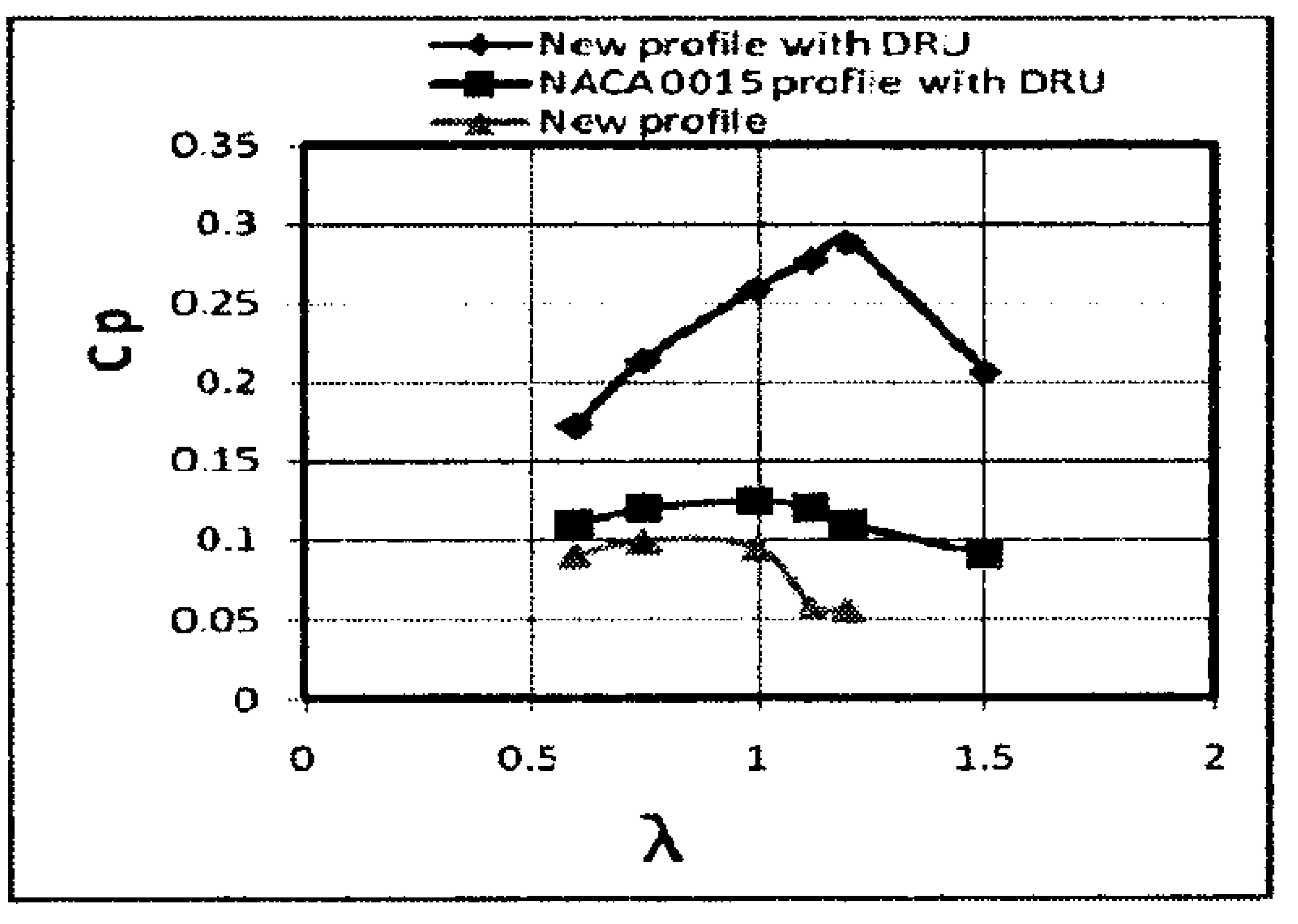



**Figure 8: Variation of power coefficient with different tip speed ratios**

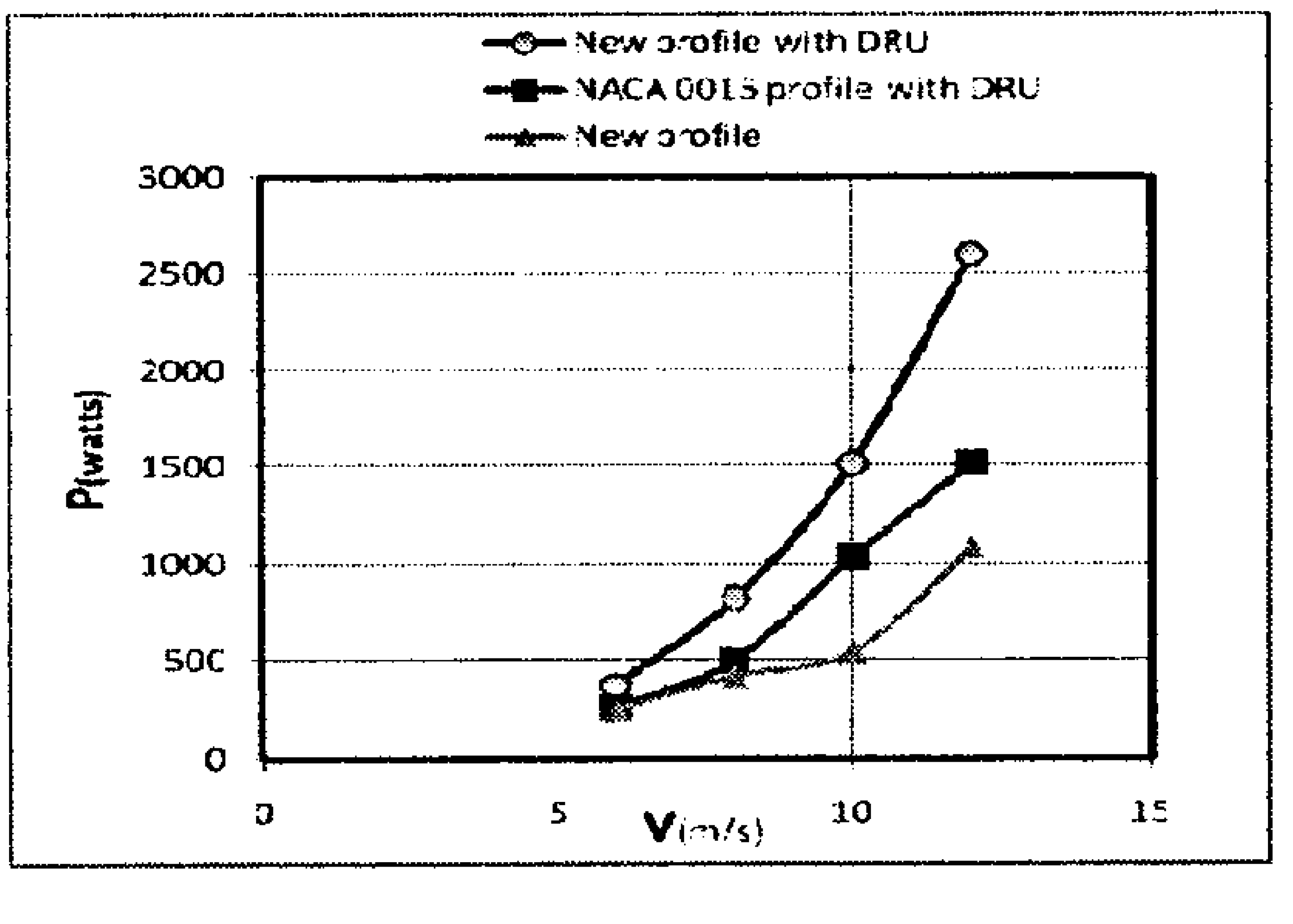



**Figure 9: Power output variation with wind speed**

Figure 9 shows the variation of power output for three turbines with different wind speeds. The new blade profile with DRU gives higher power output than other two turbines. New blade profile with DRU power output of 1500 watts can be extracted at the wind speed of 10 m/s, while other two turbines give remarkable low values than that. Therefore it is evident that S-VAWT with introduction of DRU has better power extraction ability than the S-VAWT without DRU.

*Wind tunnel test*

A wind tunnel has been designed and fabricated as shown in figure 10. Performances evaluation test of the wind turbine are carryout in order to verify the situational results.

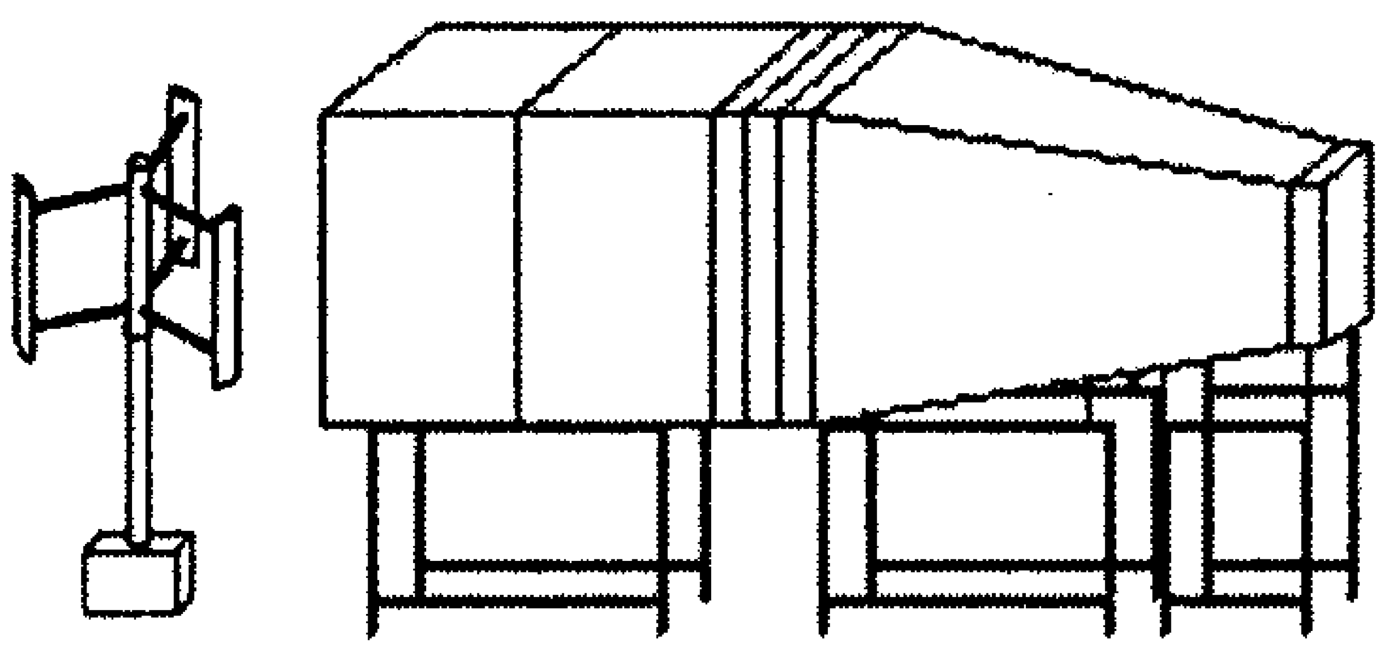


**Figure 10: Designed wind tunnel arrangement**

## Conclusion

In this study CFD simulations were conducted to investigate performance of S-VAWT with the introduction of DRU. Following conclusions are brought from the present study,

(1) A New blade profile with the DRU was design considering the maximization of coefficient of performance of the turbine.

(2) The present blade profile with DRU gives much improved performance than the existing blade profiles.

(3) It was found that maximum power coefficient for the present turbine with DRU can reach up to 0.30 at the tip speed ratio around 1.25.

## References


Anonymous (2000). *3MW Pilot Wind Power Project.* Semi-annual report on the performance July-December 2000.

Cheng, J-H. and Hu, S-U. (2008). Innovatory designs for ducted wind turbines. *Renewable Energy* 33, 1491-1498.

Narayana, M. (2009). *Validation of WRAM wind resource map and possibility to utilize wind energy for power generation in Sri Lanka.* National Engineering Research and Development Center of Sri Lanka.

Takita, H., Takao, M., Toshimitsu, K. Saito, T., Maeda, T., Kamada, Y., (2009). Experimental study of a straight-blade vertical axis wind turbine with directed guide vane row. *Proceedings of the ASMe 28th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2009* Honolulu, Hawaii paper No. OMAE2009-80081

Wakui, T., Hashizume, T., Nagao T., and Tanzawa, T. (2005). Hybrid configuration of Darrieus and Savonius rotors for stand-alone wind turbine-generator system. *Electrical Engineering in Japan* 150 (4), 13-22.

Young, M. and Vilhauer, R. (2003). *Sri Lanka Wind Farm Analysis and site Selection Assistance.* National Renewable Energy Laboratory /SR-710-34646.