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Aerodynamic Analysis of Novel Savonius Rotor

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Abstract: Wind is a renewable form of energy that holds vital solutions to energy crisis that will be faced in the possible future. Apart from the viable lift based turbines that we have been working on, research can be done on drag based turbines that can be installed in urban areas for short power requirements. The research aims at developing a novel design for Savonius type rotor which will help to improve the power producing characteristics of the turbine. CFD fluent analysis will help in analysis of the proposed blade shape. The results explain how the combination of elliptical profiled blade improves coefficient of power for Savonius type rotor.
Keywords: Aerodynamics, Wind Energy, Savonius, VAWT, Wind Turbine

I. INTRODUCTION

Wind is an essential source of renewable energy. Considering the present scenario of fossil fuel consumption, it is imperative to be advanced in extracting the maximum out of these sources for the betterment of all. Till fossil fuels provide, time is available for research in all of the available renewable sources. It has been projected that total solar power received by the earth surface is approximately 1.8 x 1011 MW per years. Out of this, only 2% 3.6 x 109 MW is converted into wind energy. Windmills were used in Persia (present-day Iran) dated back to 200 B.C. The wind wheel of Heron of Alexandria marks one of the first recorded instances of wind powering a machine in history. Conversely, the first known practical windmills were built in Seistan, a region between Afghanistan and Iran, from the 7th century [1]. All the research done till date clearly indicate we have a lot to explore and a lot to understand in this proposed future source of energy. Since the sun in our solar system is still young and will exist for million years more, solar energy and wind energy thereof is to be available for a long time. Wind turbines, usually lift-based one are developed and in practical effect since long time. The other type i.e., drag-based are not for mass production of energy. The primary aim of our analyses will be to enhance the power producing capacity in one of the drag type turbine – Savonius S type rotor. With its invention being done for the purpose of pumping water from the ground, we believe it can provide for as a reliable product; one which can easily be set-up in unconventional areas for supporting power supply to essential devices like homing devices, cell phones, small capacity portable generators and many more. This can be used even in war zone to power communication devices. They can be used in other high rise structures too for the basic purpose of small capacity power generation. Conventional Savonius type rotor is an S-type rotor which comprises of two semi-circular buckets arranged such that they share a small overlap in the centre. Apart from semi-circular buckets, shapes of the savonius rotor’s buckets have always been experimented in an attempt to observe an increase in the coefficient of power of the rotor. We have considered only semi-circular, composite shaped and elliptical shaped buckets for the whole procedure In order to meet the objective, a serious search into the already proposed ideas was taken. In each find, one or the other additional equipment played the key factor in the power enhancement of the rotor. This led us to find alternatives that don’t include additional attachments on the basis that these additional attachments would increase to the cost of production increase the weight of the overall assembly and require additional maintenance upon non-functionality as per requirements due to various external factors.

A detail description has been done in the literature survey.

A. Nomenclature

TABLE I Nomenclature

Symbol	Description	Symbol	Description
λ	Tip speed ratio	ρ	Density of Air
V	Speed of blade tip	A	Frontal area
U	Free stream velocity of wind	C_t	Coefficient of torque
C_p	Coefficient of power	T_ω	Torque available from the wind
P	Power produced by the rotor	D	Rotor diameter
P_ω	Total available wind power	H	Rotor Height
T	Torque produced by rotor	e	Bucket overlap
ω	Angular velocity of rotor	C	Chord

$$Tip\ Speed\ Ratio = \lambda = \frac{V}{U}$$

$$Power\ Produced\ by\ rotor = C_p = \frac{P}{P_\omega} = \frac{T\,\omega}{\frac{1}{2}\rho\,A\,U^3}\ ; \qquad Coeffcient\ of\ torque = C_t = \frac{T}{T_\omega} = \frac{T}{\frac{1}{4}\rho\,A\,U^2 D}$$

II. LITERATURE SURVEY

A detail literature survey was carried out to find possible solutions to improve the power producing capacity of savonius type rotor. Firstly, we will consider effect of geometrical parameters. End plate diameter has an optimum value of 1.1 times D [2] . Although we search into aspect ratio [3], blade profile [4], blade shape [5] , no clear idea could be made out as to which parameters gives out optimum result. Other parameters along with their optimum values are overlap ratio – 0.15 to 0.25 [6], number of rotor stages – 1 [7], number of blades – 2 [8]. Another concept which we came across was to reduce negative drag on returning blade. With the help of additional attachments, successful attempts have been recorded so far. This includes use of wind shields [9], use of curtain [10], and use of guide vanes [11]. These methods proved effective in reducing negative drag by blocking the wind on returning blade and divert it to the forwarding blade. The results came at the cost of added weight of the attachments and setup fixtures. Another concept of elliptical blade profiles was found out [12]. The use of convex and concave blade profile together registerd a good increment in coefficient of power, all without using any additional attachments. The only variation was the bucket shape. For future reference, their optimum values of a1 (0.3936) and a2 (0.2743) were considered for the model but dimensions were taken from hayashi [11] for the model. For CFD considerations in fluent, k–ω SST (Shear-Stress Transport) turbulence model produced more accurate predictions of the Savonius rotor performance [13]. Also sliding mesh technique produced more accurate results than static analysis.

III.HYPOTHESIS

Various type of drag forces are acting on the rotor like parasite drag, induced drag and wave drag. The main aim is to reduce form drag which is a part parasite drag. Form drag is generated due to the shape of the body. Form drag is caused by difference between the pressure distributions over a body. It is well known that an objects shape plays a significant role in the drag produced while subjected to a free stream flow. The Savonius wind turbine works due to the difference in forces exert on each blade. Because of the curvature, the blade experience less drag when moving against the wind (returning blade) than when moving with the wind (advancing blade). The differential drag causes the Savonius turbine to spin. Conventional Savonius blade has semi-circular shape on convex and concave side. In this approach, novel composite blade profile is proposed in order to reduce drag on returning blade. The composite blade has semi-circular shape on concave side and elliptical shape on convex side. In this section, two composite blade profile (H/D ratio = 1.5 and 2) and a semi-circular blade profile are consider for analysis as shown in Figure 1.

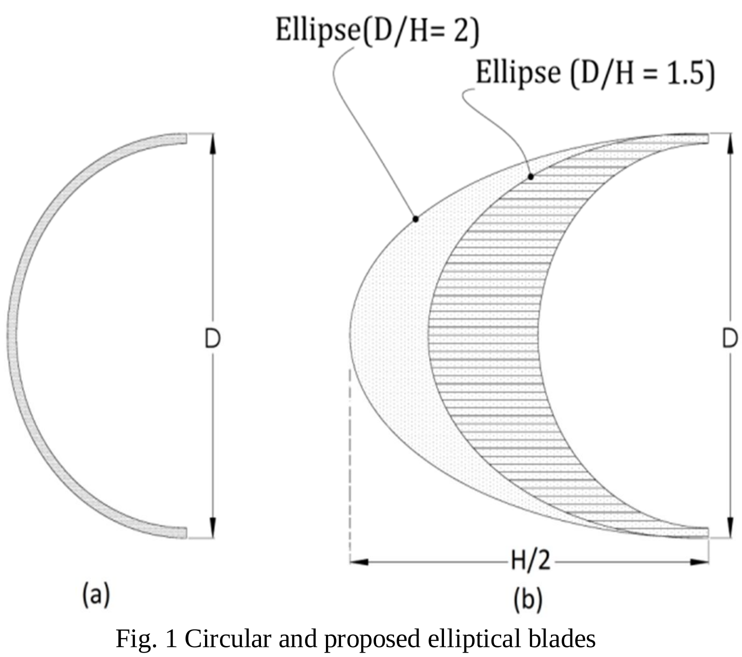

Fig. 1 Circular and proposed elliptical blades

In order to determine blade profile having least drag coefficient, transient flow analysis has been performed for conventional semi-circular blade and novel composite blade profiles. Numerical analysis has been performed to measure drag forces on blade profile using fluent. For static analysis, CAD model was prepared in geometry modeller itself considering optimal wind tunnel domain dimensions. The Domain width is 60D, upstream length 40D and downstream length 100D. D – Diameter of blade is 1m for the static analysis consideration. The schematic of wind tunnel 2D is as shown in Figure 2.

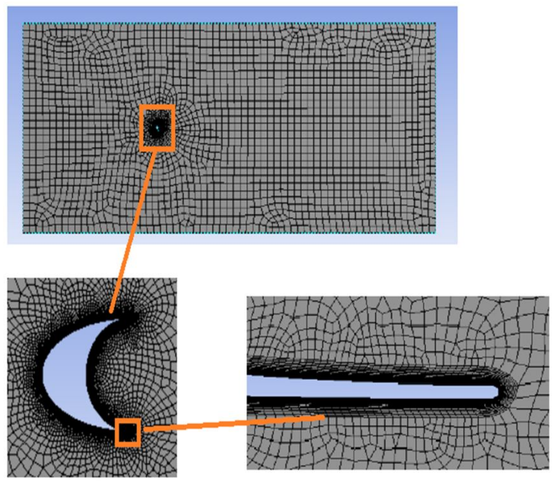

Fig. 2 2D Computational domain layout

For Static analysis, semi- circular blade, elliptical blades of H/D = 1.5, 2, 2.5 and Tian blade – all of 1m diameter; were tested for Reynolds numbers 3.42 x 105, 6.84 x 105 and 10.26 x 105. A refined grid with inflation is imposed in the boundary layer of the blade with minimum 20 levels of rectangular cells, shown in Figure 3. For analysis, parallel processing was selected and the grid was partitioned into 4 parts of the same computational weight using auto portioning in Fluent in order to reduce the computational time by 60-70% [14]. The solver is set as pressure based with absolute velocity formulation. The time step size was calculated from Reynolds number and maximum number of iterations set to 200. Turbulence model k- ω SST, momentum equation and transient formulation set to second order upwind. The mesh details are discussed in Table II.

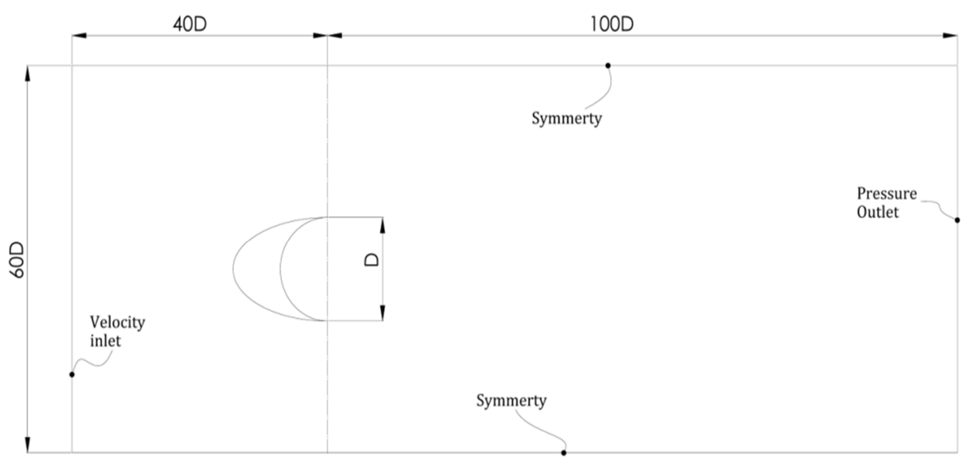

Fig. 3 Mesh for static analysis

The process continues with dynamic analysis to verify the answers obtained in static analysis. The semi circular rotor model dimensions of Hayashi [11] were considered for the semi circular model and a mesh independent test was conducted on a 2D wind tunnel domain with semi-circular blade in it to verify which mesh would yield the best result in least computation time. The 2D wind tunnel domain is shown in Figure 4 and its details are discussed in Table III.

TABLE III
MESH DETAILS

Description	Semi-circular profile	Composite blade profile (H/D ratio = 1.5)	Composite blade profile (H/D ratio = 2)	Composite blade profile (H/D ratio = 2.5)	Tian blade profile
Number of Node	87946	91365	95136	97435	71686
Number of Element	86403	89773	93468	95736	70431
Min. orthogonal quality	0.2483	0.2498	0.3293	0.3405	0.3443
Min. ortho skew	0.7516	0.673435	0.6706	0.6594	0.6556
Max. Aspect ratio	56.6626	39.883	53.7263	67.0497	33.7465
First layer height	0.0000459 m	0.0000459 m	0.0000459 m	0.0000459 m	0.0000459 m

The global mesh included quadrilateral elements with minimum size of 1 mm and maximum size as 50 mm. The growth rate was set to 1.10. The mesh configuration is shown in Figure 5. The sizing details are provided in Table IV. For dynamic analysis wind velocity is taken as 9 m/s and semi-circular, elliptical H/D = 1.5 and 1.25, Tian blade and elliptical H/D =0.8 were considered as H/D = 2, 2.5 provided inconsiderable results in primary analysis. For this problem sliding mesh analysis is performed to get accurate results. In sliding mesh analysis angular rotation is applied to rotor domain and wind tunnel domain is kept stationary. Both blades have been given rotational motion about its axis with respect to adjacent cell zone as a boundary condition wind velocity magnitude is given at inlet and atmospheric pressure at outlet. The wind tunnel domain and rotor domain interface was reconstructed after rectifying the need to undo auto-interface as it hindered in the analysis. The reference value area is 0.33 m^2, length is 1.65 m. Solution includes Pressure velocity coupling, scheme – SIMPLE, gradient – least squares cell based, pressure – second order, momentum – second order upwind, turbulent kinetic energy and turbulent dissipation rate as second order upwind and transient formulation as second order implicit. Solution was initialized from the inlet. Complete revolution comprised 250 time steps.

TABLE IIIII
2D MODEL DETAILS FOR DYNAMIC ANALYSIS

Sr. No.	Description	Value
1	Width of Wind-Tunnel domain (20 D)	6.6 m
2	Upstream length (10 D)	3.3 m
3	Downstream length (15 D)	4.95 m
4	Rotor domain diameter (1.4 D)	0.462 m
5	Rotor diameter (D)	0.33 m
6	Chord (Blade diameter)	0.198 m
7	Blade thickness	0.002 m
8	Overlap ratio (e/D)	0.2
9	Shaft diameter	0.015 m

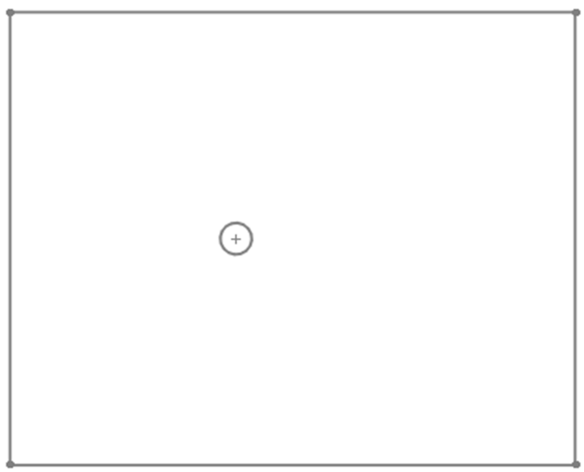

Fig. 4 2D model for dynamic analysis

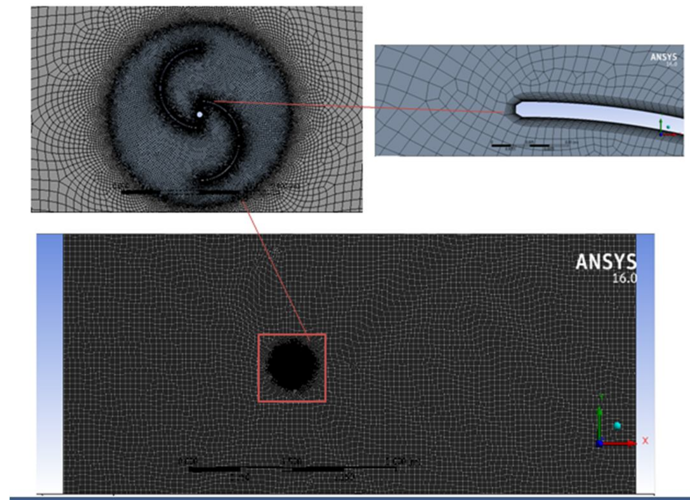

Fig. 5 Mesh configuration for dynamic analysis

TABLE IVV
Mesh size for Dynamic Analysis

Sr. No.	Description	Size (in metres)
1	Wind tunnel – Face meshing	0.025
2	Rotor domain – Face meshing	0.005
3	Outer interface – Edge sizing	0.002
4	Inner interface – Edge sizing	0.002
5	Forward and Return blade – Edge sizing	0.001
6	Blade thickness- Edge sizing	5 divisions
7	Rod – Edge sizing	0.001
8	Blade – Inflation	15 layers (First layer thickness – 0.00004) (Growth rate – 1.1)

IV. RESULT

The static analysis performed on the elliptical blades yielded an expected decrease in the drag coefficient. The velocity contours at Reynolds number 10.26 x 105 for semi-circular, Elliptical H/D = 1.5, 2, 2.5 are provided in Figure 6. Plot of C_d vs. Wind speed is shown in Figure 7. As observed from the figure, the elliptical blade profiles registered a reduce drag coefficients. This means we can use them to reduce drag on the returning blade. However, preliminary analysis using these profiles in dynamic analysis yielded drastic reductions in coefficient of power. It is for this reason that dynamic analysis for H/D = 2 and 2.5 were suspended as we failed to acknowledge the dynamic torque effect and only preceded with static torque considerations. In new search, Tian [12] blade dimensions were adapted to our hypothesis considering only a1 and a2 values from it. These values were used to calculate H/D ratios for outer and inner blade of the bucket which were 0.7872 and 0.5486 respectively. The newly found blade registered even greater decrease in drag compared to previous elliptical models. The model was then taken in dynamic analysis to calculate its coefficient of power (C_p). In other attempts, new blade with H/D ratio of 1.25 was taken in dynamic analysis to check if it could provide better C_p than conventional semi-circular bladed rotor.

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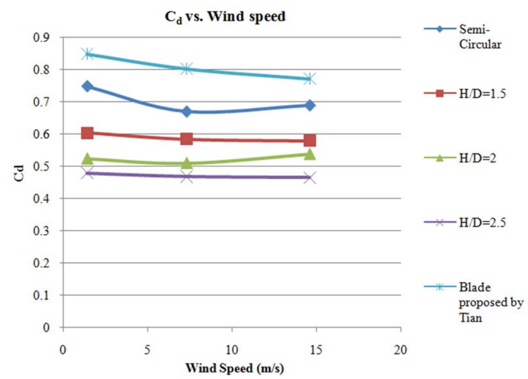

Fig. 6 Comparison between C_d and Wind speed

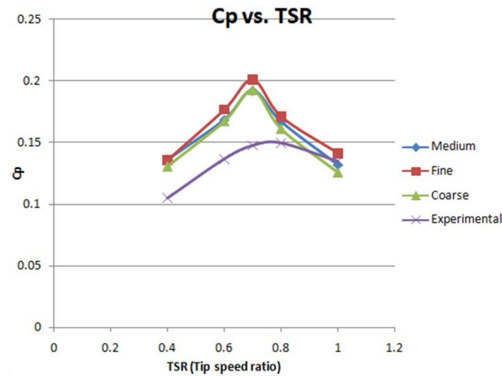

Fig. 7 Comparison between C_p and Wind speed

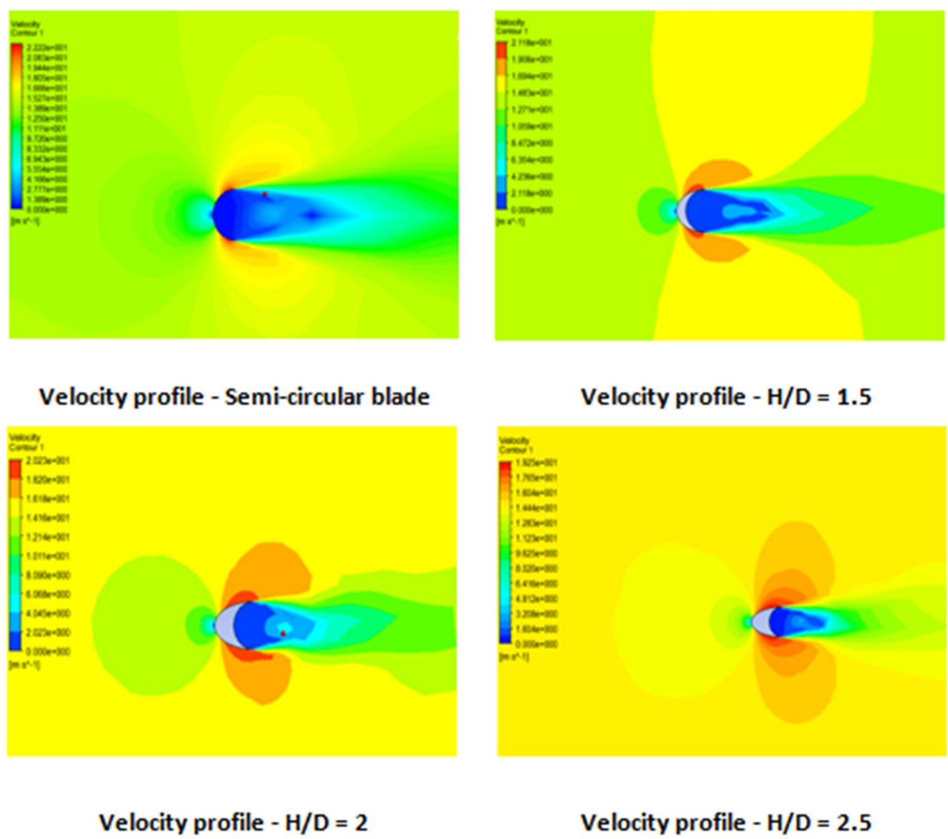

Fig. 8 Velocity Profiles

Starting with mesh independent test, 3 mesh configurations namely coarse, medium and fine were considered and the rotor revolutions were 25. Semi-circular model based on Hayashi [11] experimental data was considered for mesh independent test at tip speed ratios 0.4, 0.6, 0.7, 0.8 and 1.0. The results of mesh independent test are displayed in Figure 8. As evident from figure 8, medium mesh yielded results nearer to experimental data and thus was confirmed for dynamic analysis. The medium mesh details are discussed earlier in Table 3. After mesh independent test, series of dynamic analysis were carried out and Tian [12] based model provided maximum increment in coefficient of power compared to semi-circular or other elliptical blades. Lastly, a new blade with H/D ratios 0.8 for both outer and inner blade was considered for dynamic analysis. The new blade registered coefficient of power similar to Tian [12] based model. The results of dynamic analysis can be observed in Figure 9. As seen in figure 9, H/D = 0.8 blade almost converges with the Tian [12] based rotor model. Thus, I concluded analysis with H/D = 0.8 blade profile.

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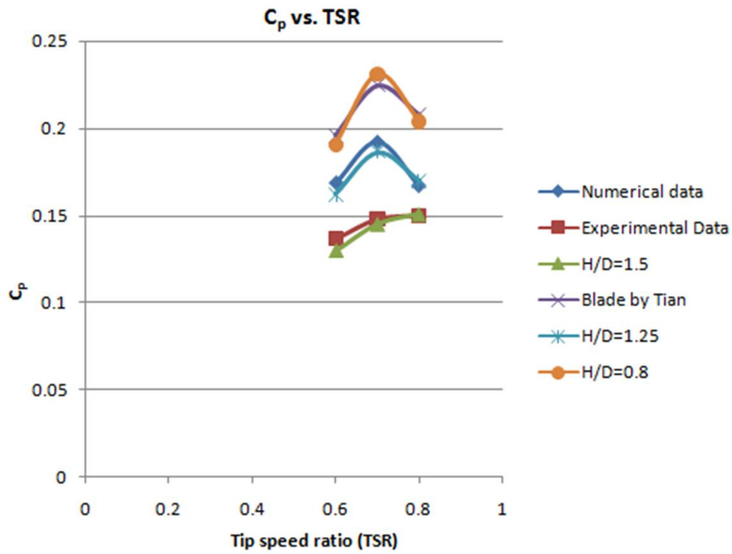

Fig. 9 C_P Vs. TSR

V. CONCLUSION

After a series of static and dynamic analysis, I concluded the following:

1) Static analysis of elliptical blade profiles (H/D = 1.5, 2, 2.5) proved reduction in coefficient of drag.
2) Dynamic analysis of elliptical blade profiles (H/D = 1.25, 1.5, 2, 2.5) failed to produce any significant increment in coefficient of power for savonius rotor model.
3) Tian [12] based rotor model provided significant increment in coefficient of power. Hence, their model stays validated.
4) Optimal blade profile with H/D ratio 0.8 for both outer and inner blade of the bucket showed results similar to Tian [12] based model.

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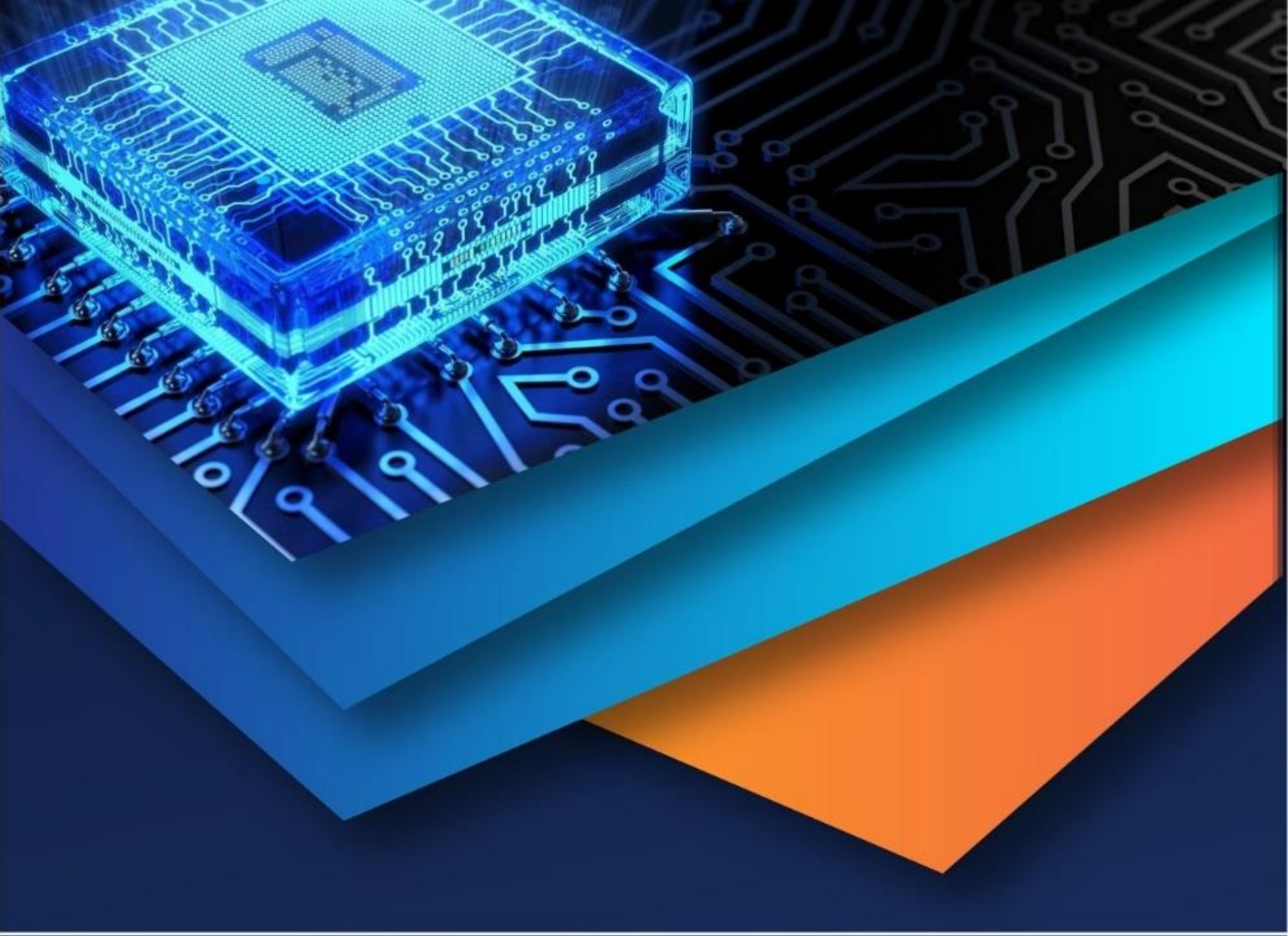

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