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Numerical Simulation And Aerodynamic Performance Comparison Between Seagull Aerofoil and NACA 4412 Aerofoil under Low-Reynolds[1]

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Abstract: For the aerofoil of small wind turbine working under the conditions of low-Reynolds, the aerodynamic performance of seagull aerofoil and NACA 4412 is contrastively analyzed while the Reynolds-Number is 1×10^5 、 3.5×10^5 and 6×10^5 by the Fluent. The numerical simulation comparison shows that, when the attack-angle range is 0°~20°, the life-coefficient of seagull aerofoil increased 24.97%、46.02% and 48.54% than NACA 4412 respectively; when the attack angle is 4°, the lift-drag ratio of seagull aerofoil increased 40.44%、43.14%和 39.40% than NACA 4412 respectively. Under the condition of Reynolds-Number is 6×10^5, the normal working range of attack angle of seagull aerofoil increased 16.7% than NACA 4412 .Under the same simulation condition, the separation point of NACA4412 aerofoil is closer to the leading-edge than seagull aerofoil . The analysis shows that the unique distribution of

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the thickness and the camber of the seagull aerofoil is the main reason of the better aerodynamic characteristics under the Low-Reynolds.

Keywords: Low-Reynolds; wind turbine; aerofoil; numerical simulation; aerodynamic characteristics

1. INTRODUCTION

The paddle is the core component of wind driven generators when capturing wind energy. Its performance directly affects the availability of wind energy of wind driven generators. Thus, the design of the paddle is an important research and development task of wind driven generator technologies. Early paddles of wind driven generators were designed and developed based on propellers, and mostly used the NACA series airfoil. However, the working Reynolds numbers of small-power wind driven generators are relatively low and the air viscosity has relatively great influence on paddles, so the use of traditional airfoil is difficult to work efficiently in such bad conditions (Michael et al., 1996).

Bionics researches find that after almost one hundred million years' evolution, the airfoil of birds has better aerodynamic performance, particularly seagulls with very good performance of glide. When they are flying, the relative speed with air is similar with the relative speed that paddles are with air when small-power generators normally work. This article creatively combines the design of wind driven generators airfoil with the idea of bionics, extracting the seagull airfoil through consulting materials. It also analyzes the specific performance under the Low-Reynolds numbers by using the Fluent software in order to simulate its working performance that is installed upon small-power wind driven generators and the results together with the NACA 4412 airfoil results are compared and analyzed. A seagull's wing is shown as in Fig. 1(LIU et al.).

Fig. 1: A Seagull's Wing (LIU et al.)

2. NUMERICAL SIMULATION METHOD

2.1 The S-A Turbulent Flow Model

The S-A turbulent flow model is specially designed for aerospace field in its research on the wall boundary flows, which is mainly used to properly solve the areas of boundary layer that is affected by viscidity and has a better convergence toward solid wall turbulence flow (Franck & Niels, 2001). The S-A model is not directly simplified by the k-ε equations model, but begins with the analysis of experience and dimension. It is an equation model that develops gradually from the simple flow and is suitable for the laminar flow with turbulent flow of solid wall. The S-A model has the characteristics of easy and quick convergence and better results can be achieved when calculating the pressure gradient boundary layer flow. It is widely used in numerical calculation of turbine machinery. The S-A model transport equation is given below (LI, 2009; MUELLER, 1985).

2.2 Grid Division and Boundary Condition Settings

In this paper, the numerical simulation airfoil models are seagull and NACA 4412 airfoils. Fig. 2 shows the grid division situation in the whole computing domain. Fig. 3 shows the grid division situation of the near-wall part of the two airfoils. The entire computational domain extends to the location that is 25 times of chord from the airfoil surface and the outside part is dealt with as far-field pressure. Suppose the chord length c = 200mm and the airfoil locates on the center of Semicircle. A total of 10 layers are added near the wall boundary of the airfoil. The distance from the first layer of the grid to the wall is 0.1mm and the corresponding dimensionless distance y+ <10.

In the Simulation calculation, a coupled solver is used; fluid material is supposed to be ideal gas; momentum is in the form of second-order upwind dispersed mode; pressure and velocity coupling uses the SIMPLE algorithm and airfoil surface is the no-slip thermal isolation boundary.

In this paper, 500W small-power wind driven generators are used as a design goal. The rated wind speed is 9m/sec, the wind wheel diameter is 2.3 m, the rated rotational speed is 350 r / min and the mean chord length is 20cm. By calculation, we can get that the range of Reynolds number is 100,000 <Re <600,000 when paddles are at work, in which the apex Reynolds number is 600,000, blade root Reynolds number is 100,000 and the central blade Reynolds number is 350,000. Thus, we can determine the initial boundary conditions of pressure far field, as shown in Table 1. When calculated, the size of the angle of incidence is changed by changing the direction of the incoming flow. The range of the angle of incidence is 0°- 20°.

Table 1: Initial Boundary Condition of Pressure Far Field

Reynolds Numbers	Static Pressure / Pa	Velocity / m/s
100000	101292.4	7.3
350000	100925.8	25.5
600000	100156.5	44.7

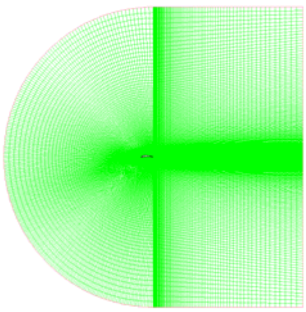
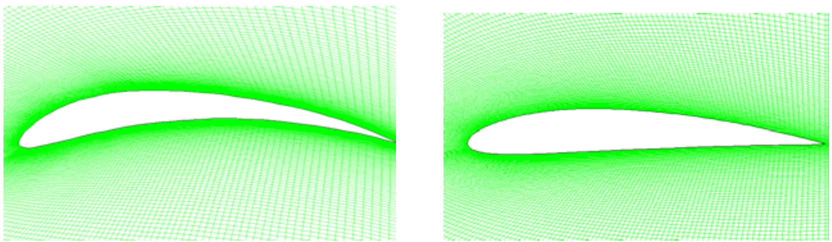


Fig. 2: Grid Division Situation of Calculation Domain



(1) Seagull Airfoil (2) NACA 4412 Airfoil

Fig. 3: Grid Division Situation of the near-wall part of airfoils

3. RESULTS OF CALCULATION

Fig. 4 compares the lift coefficient of seagull airfoil with NACA 4412 airfoil. It can be found that in all the Reynolds number, the lift coefficient of seagull airfoil is more than that of the NACA 4412 airfoil and at higher Reynolds numbers (Re=3.5×10^5 and 6×10^5), the seagull airfoil's critical angle of incidence α_c is 14°, while the α_c of NACA 4412 airfoil is 12°. With the angle of incidence increasing, the separation area of the airfoil surface increases, resulting in the loss of kinetic energy. Part of the lost kinetic energy changes into internal energy and potential energy. Thus, the pressure on the airfoil surface increases, the suction decreases, the elevating force decreases, drag force increases, and under the same angle of incidence, the more is the Reynolds numbers, the more is the lift coefficient. Fig. 5 compares the drag force coefficient of seagull airfoil with NACA 4412 airfoil. It can be found that there is not great different from these two coefficients. Fig. 6 shows the situation of lift-drag ratio of two airfoils under different Reynolds numbers. We can find that the lift-drag ratio increases first and then decreases with the enhancing of angle of incidence, and the performance of seagull airfoil’s lift-drag ratio is better than that of the NACA 4412 airfoil.

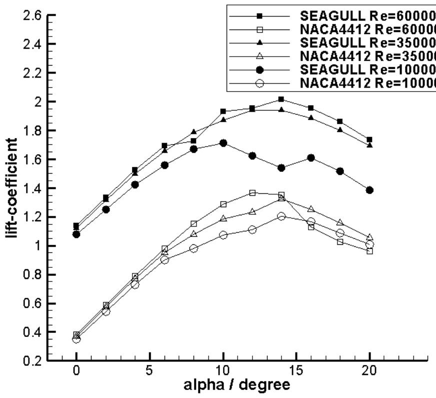


Fig. 4: Comparison Chart of Lift Coefficient of Seagull and NACA 4412 Airfoil

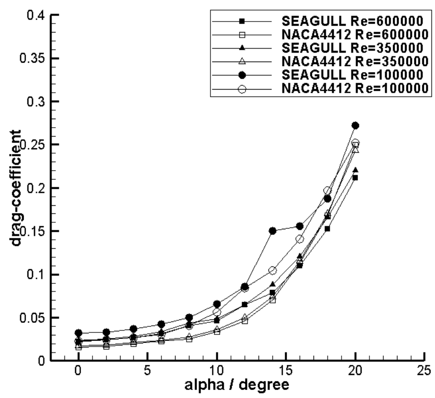


Fig. 5: Comparison Chart of Drag Coefficient of Seagull and NACA 4412 Airfoil

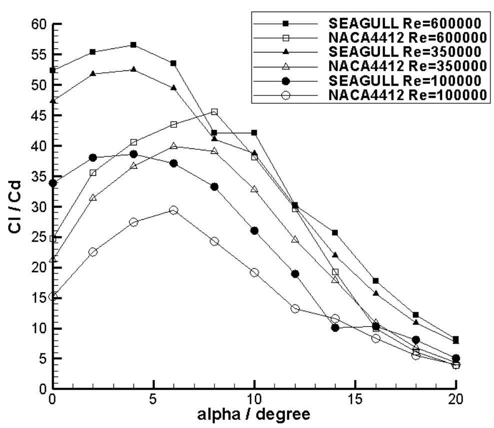


Fig. 6: Comparison Chart of Lift-drag Ratio of Seagull and NACA 4412 Airfoil

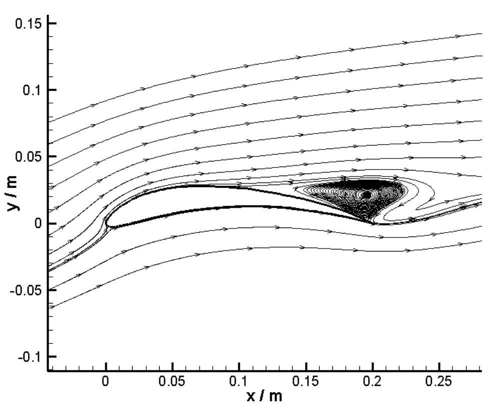


Fig. 7: Flow Chart of Seagull Airfoil When Re=100000 and Angle of Incidence=14

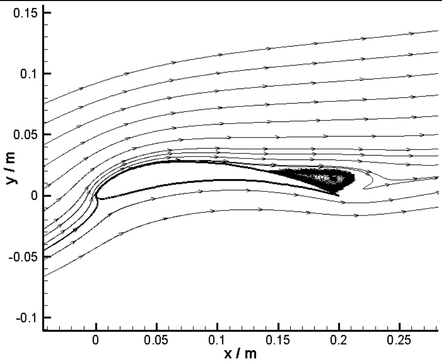


Fig. 8: Flow Chart of Seagull Airfoil When Re=350000 and Angle of Incidence=14°

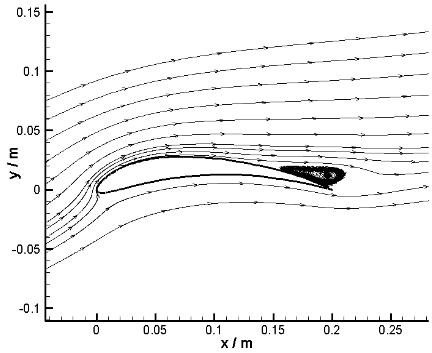


Fig. 9: Flow Chart of Seagull Airfoil When Re=600000 and Angle of Incidence=14°

When the Reynolds number is $1' \ 10^{5}$ and $a =$ 10°, seagull airfoil reaches a critical angle of incidence. This is because that at this time, the air viscosity plays an important role on the flow. Boundary layer on the surface of airfoil, under the action of adverse pressure gradient, when $a =$ 10°, a larger flow separation on the surface appears, which makes the lift coefficient decrease. Fig. 7, 8 and 9 show the flow chart of airfoil when $a =$ 14°and Reynolds numbers are respectively $1' \ 10^{5}$, $3.5' \ 10^{5}$ and $6' \ 10^{5}$. It can be found that with the Reynolds number increasing, the role of air viscosity decreases; the area of the separation of the upper surface of decreases at the same angle of incidence and the performance improves.

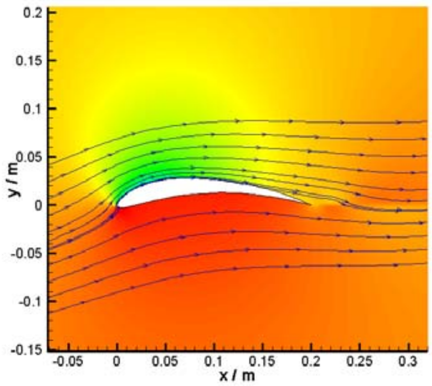


Fig. 10: Pressure Contour of Seagull Airfoil When Re=350000, 10°

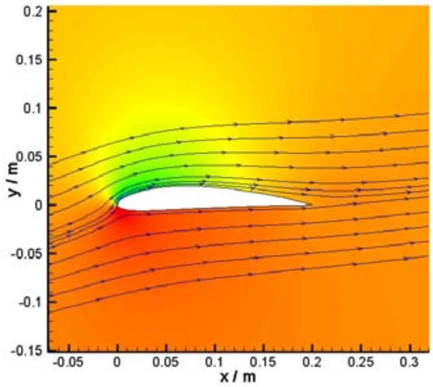


Fig. 11: Pressure Contour of NACA 4412 Airfoil When Re=350000, 10°

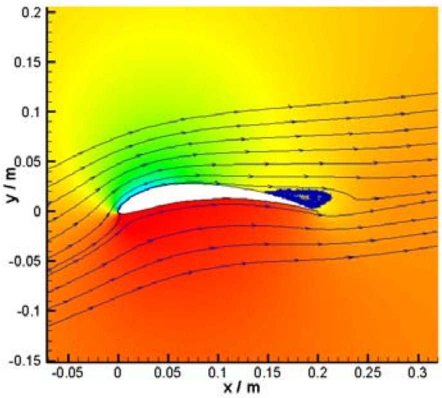


Fig. 12: Pressure Contour of Seagull Airfoil When Re=350000, 14°

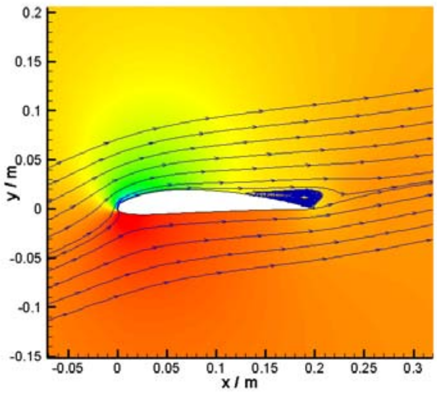


Fig. 13: Pressure Contour of NACA 4412 Airfoil When Re=350000, 14°

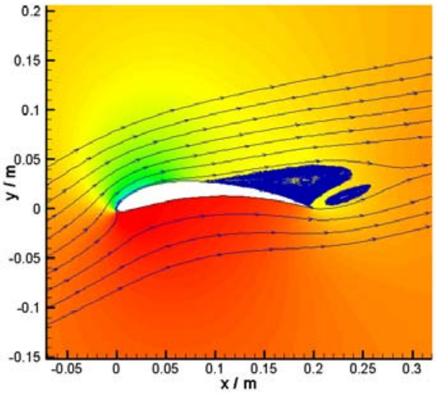


Fig. 14: Pressure Contour of Seagull Airfoil When Re=350000, 18°

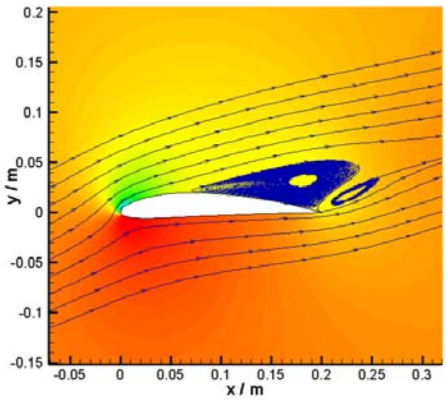


Fig. 15: Pressure Contour of NACA 4412 Airfoil When Re=350000, 18°

Fig. 10-15 show the pressure contours of seagull and the NACA 4412 airfoils when the Reynolds number is 350000 and angle of incidence is 10°, 14° and 18°. Flow lines are also marked out in the contours. It can be found that under the same condition, the suction of upper surface of the seagull airfoil is greater than that of the NACA 4412 airfoil and the area of the rear separation zone of seagull airfoil is smaller than that of the NACA 4412 airfoil.

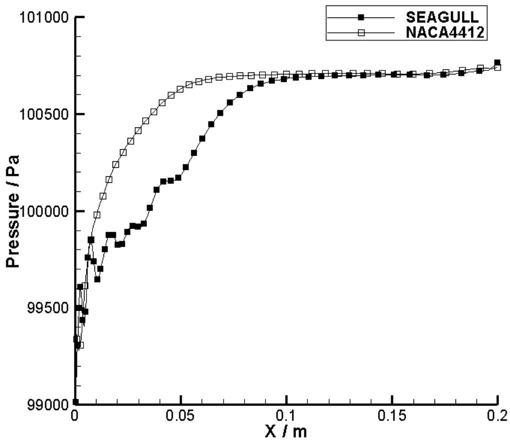


Fig. 16: Chart of Upper Surface Pressure Distribution of Seagull and NACA 4412 Airfoils When Re=350000, Angle of Incidence=18°

Fig. 16 shows the pressure distribution curve on the suction surface of these two airfoils when the Reynolds number is 350,000 and angle of incidence is 18°.We can find that the separation point of the NACA4412 airfoil is in front of 15% of the chord length than that of the seagull airfoil. This result goes a further step to show, the upper surface of the NACA4412 airfoil is more likely to appear flow separation than the seagulls airfoil.

Table 2: The List of Parameters Comparison of Seagull and NACA4412 Airfoils

	The Greatest Thickness /c	Location of the Greatest Thickness /c	The Largest Camber /c	Location of the Largest Camber /c
Seagull Airfoil	9.83%	23.4%	9.91%	43.6%
NACA4412 Airfoil	12.02%	30.0%	4.00%	40.0%

Through analysis, we can see that the seagull airfoil has larger camber and the thickness is smaller, which leads to the different performance of above. When the range of angle of incidence is 0°-20°; the

Reynolds numbers are 1×10^5, 3.5×10^5 and 6×10^5, and for the seagull airfoil, α_c is 14° and α_{ad} is 4°, seagull airfoil has higher lift coefficient, greater scope of the working angle of incidence and higher lift-drag ratio than the NACA 4412 airfoil. Parameters of seagull and NACA4412 airfoils are shown in Table 2.

4. CONCLUSION

This paper, using the results of foreign bionic experimental airfoil, makes use of the Fluent software to carry out numerical imitation and analysis of the seagull airfoil and compares with the NACA 4412 airfoil. The results show that the performance of seagull airfoil is superior to the NACA 4412 airfoil and it is suitable for small-power wind driven generators.

The main conclusions are as follows:

(1) When the range of angle of incidence is 0°-20° and the Reynolds numbers are 1×10^5, 3.5×10^5 and 6×10^5, seagull airfoil has higher lift coefficient, greater scope of the working angle of incidence and higher lift-drag ratio than the NACA 4412 airfoil. The seagull airfoil lift coefficient increases 24.97%, 46.02% and 48.54% over the NACA 4412 airfoil. When for the seagull airfoil, α_{ad} is 4°, the lift-drag ratio increases 40.44%, 43.14% and 39.40% over the NACA 4412 airfoil.

(2) In the high Reynolds numbers (Re=3.5×10^5 and 6×10^5), for the seagull airfoil, α_c is 14°, which is larger than that of the NACA 4412 airfoil whose α_c is 12°. And the normal working angle of incidence increases 16.7% than that of the NACA airfoil.

(3) Under the same circumstances, the upper surface of the NACA4412 airfoil is more likely to appear separation than the seagull airfoil and the separation area is larger than the seagull airfoil. When the Reynolds number is 3.5×10^5 and angle of incidence is 18°, the separation point of the NACA 4412 airfoil is in front of 15% of the chord length than that of the seagull airfoil.

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