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Numerical Study for Slotted and Vibrating Asymmetric Aerofoils

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Abstract

The aerodynamics of slotted asymmetric and vibrating aerofoils under various Reynolds numbers were numerically studied. Various Reynolds numbers, (0.25, 0.4, 0.7 and 1) $\times 10^6$ and different number of time step, (500,1000, and 2000), were employed using an Ansys 22 R1 noncommercial version. The mesh around the aerofoils was chosen by conducting a case study then compared to a previous experimental work. A slotted asymmetric NACA4412 aerofoil was chosen to implement the concept of the current investigation. The aerodynamics of the normal shape of NACA4412 was validated with a previous experimental work. The slot technique can provide more momentum to the flow along the aerofoil. Moreover, the two aerofoils shapes then subjected to an 1Hz oscillatory motion due to the wind flow and the slotted aerofoils showed 10% better aerodynamics than that from the normal shape when increased Reynolds number values.

Keywords: Reynolds numbers; CFD; Lift force; Slot; Asymmetric; Aerofoil; Vibrating

الخلاصة:

تمت دراسة الديناميكا الهوائية للجنيح ذو الشقوق مع أرقام رينولدز المختلفة عددياً. تم استخدام أرقام رينولدز المختلفة (0.25، 0.4، 0.7 و1) $\times 10^6$ باستخدام إصدار Ansys غير التجاري. تم اختيار الجنيح غير المتماثلة ذات الشق ، والذي كان NACA4412، لتنفيذ مفهوم البحث الحالي. تمت مقارنة الجناح الهوائي الأساسي بجناح يحوي على شقوق. يبدو أن الجناح المشقوق يتمتع بزخم أكبر على جانب الشفط. أظهرت النتائج أن قوة الرفع تتعزز مع الفتحة عند زيادة قيمة رقم رينولد. وكذلك تم تعريض الجنيح المشقوق الى اهتزاز بقيمة 15 هرتز نتيجة تعرضه للهواء واظهرت النتائج تفوق الجناح المشقوق على نظيره العادي بنسبة 10% تقريبا مع تزايد قيمة رقم رينولدز.

1. INTRODUCTION

Enhance the aerodynamics of wind turbines has become an important factor to absorb high energies from wind machines. More recent, researchers have initiated to modified the structures of wind turbines or aircrafts wings to gain more efficiency. Many researchers have targeted the shape of the aerofoil in order to study the effect of the shape on aerodynamics of aerofoils. Many modifications have been conducted. One of these modifications is a slot. The slot can be considered a vertical or inclined distance between the upper and lower curves of aerofoils passing through the chord line. A group of research was utilised symmetric and asymmetric aerofoils [1], ANSYS CFD was used for experimental and numerical work at high Reynolds number and angles of attack. Three non-slot aerofoil shapes were examined, two of which were symmetrical and one asymmetrical. The simulation of the NACA 0015 aerofoil, which had a slot after 40% from the nose of the aerofoil, was achieved numerically. In comparison to the base blade, the modified NACA 0012 blade performed better at high angles and with fluctuating flow. Generally, improved results by a slot technique can be taken into consideration, particularly in situations with unstable wind flow. An asymmetric aerofoil studied by [2] used the NACA4412 aerofoil's aerodynamic efficiency at a moderate Reynolds number calculated from the chord length of the aerofoil and Re = 200,000. It was discovered that while uniform suction increased aerodynamic efficiency. Aerodynamic efficiency was increased by uniform flow when it was applied to the pressure side using Re = 10,000,000. Based on the results, it may be able to tentatively control effect of a wider range of Reynolds numbers. [3] found a way to improve the aerodynamics of the aerofoil used for wind turbine blades, aeroplane wings, helicopter propellers and other applications is the primary goal of the current study (like NACA 4412). A slotted aerofoil was utilised to overcome the separated flow at high angles of attack. [4] demonstrated that a slotted aerofoil can enhance the maximum thrust of a UH-60A helicopter wing by up to 25%. However, at high angles of attack, there was a noticeable increase in drag. On the other hand, a numerical analysis of the curved shape slot NACA 2412 aerofoil with at Re (1.7×10^6) was conducted. The flow surrounding the aerofoil was simulated using the SST k-ω turbulence model. Moreover, a work performed by [4] employed at various angles of attack AOAs, a numerical and experimental examination was conducted with a Re number of 10^5. The findings demonstrated that there was no influence on angles of attack between 0 and 10 with the slot, but the lift coefficient still increased at these high angles. The drag coefficient decreased. An experimental work was conducted by using a passive propeller slot at Re number 1.6×10^6. The outcomes demonstrated that for one of the finest situations studied, the lift coefficient improved by up to 30%, while a negligible increase in drag was noted, [5,6]. A cambered (asymmetric) aerofoil of the blade of a vertical axis wind turbine, was numerically studied by [7]. At different angles of attack, the operation of the cambered NACA 4415 and symmetrical NACA 0012 blades were investigated. The cambered turbine showed better self-starting than the symmetric aerofoil. Nonetheless, the cambered blade had a high lift force. [8] demonstrated that, at low AOAs, a slotted aerofoil increased a helicopter's thrust force by 25% despite the high drag. In addition, [9] tested experimentally and numerically the slotted S809 aerofoil at different AOAs. There was an obvious separation with high AOAs. [10] investigated a slotted blade using numerical and experimental methods. The study exposed that at high angles of attack, the lift increased by 58% and the flow separation was delayed to near the trailing edge [11]. A study was motivated by [12] to support the necessity of supporting flow using the slot technique on the lower side of a NACA4412 aerofoil at a Reynolds number up to 10^5.

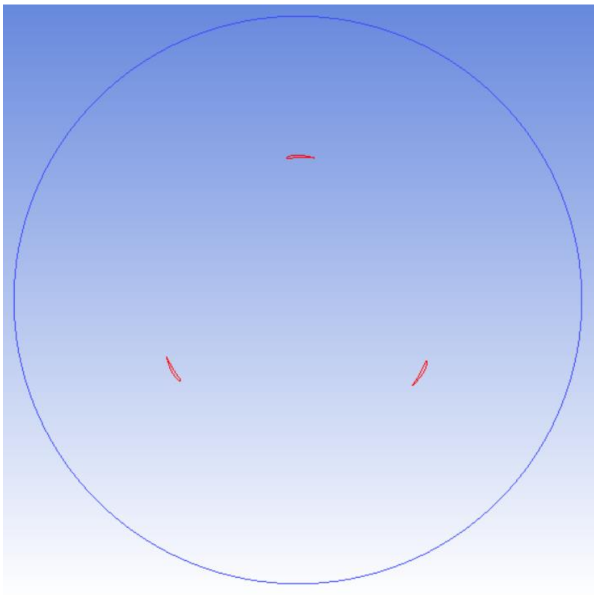
According to vibrating shapes, [13,14] searched on the harmonic motion of a 2D cylinder. A numerical solution was conducted using the dynamic mesh technique and a UDF file. The study recommended to use the same approach to different vibrating solid shapes.

The article may mostly cover all studies of the available literature on this topic, that would pave the way for interested researchers to plan their future works on a similar topic. The article reviews search studies on the effect of a different shape of aerofoils on aerodynamics of wind machines. Additionally, the effect of vibrating aerofoils because of the flow, was also investigated. There is no change in the AOA includes in the current study in whole cases.

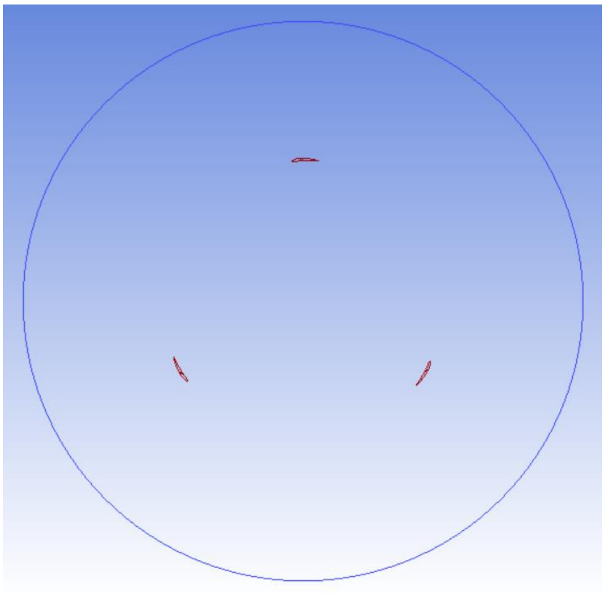
2. NUMERICAL WORK

2.1 Geometry

The ICEM Ansys tool was employed to simulate the behaviour of flow on aerofoils. Two shapes of NACA 4412 aerofoils were selected in the current search. The normal model is a NACA 4412 aerofoil with a constant chord c = 100 mm. While the other is the slotted aerofoil. The two shapes were utilised to build a 2D vertical wind turbine. Three aerofoils (with and without slot) were set inside a circle which represents the fluid domain around them. Furthermore, another geometry was built and set in a similar way but with slotted aerofoils, see Figure 1. The geometry of the slotted aerofoil was created with a 4 mm and 32% of the chord of the NACA 4412 aerofoil which is similar to a previous study [1].



(a)



(b)

Fig. 1 Geometry of the study, without slot (a) and with slot (b).

As seen in Figure 2, the slot is a passage that connects the low-pressure side of the aerofoil's, which is the upper surface, with its high-pressure side at the lower surface. Three slot parameters; the width, slope, and location on were taken into account. The values of the parameters were similar to that used in [1], which were less than 10% of chord, 60° and 40% of chord respectively.

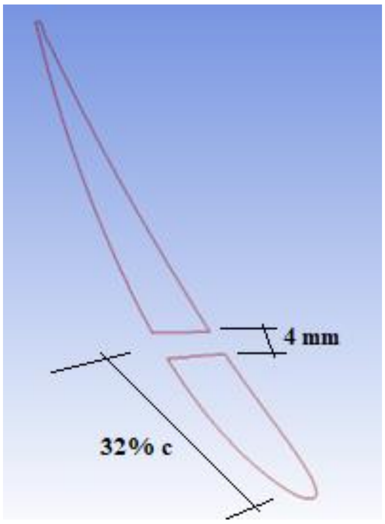


Fig. 2 Zoom in view for geometry of the study with slot.

The outer domain, which represents the test section of a wind tunnel, was constructed above the inner domain, as shown in Figure 3. The full domain can mimic the rotating of a vertical wind turbine. The outer domain includes main parts; inner, outer wall, and circle in the middle. The circle permits the fluid around the aerofoils to rotate smoothly when interface with the inner domain.

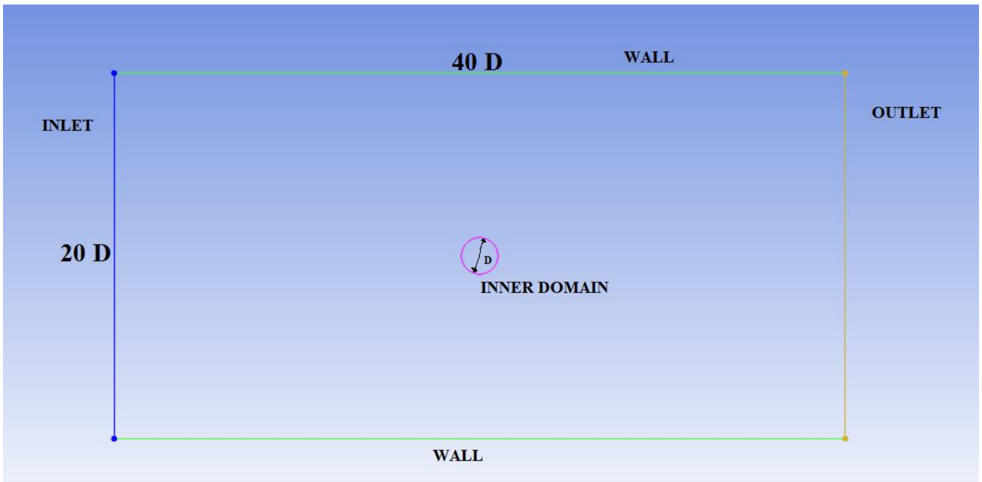


Fig. 3 The computational domain

2.2 Mesh of the full domain

The meshing grids are the smaller discretized units that resulted from the domain and model of consideration geometries. The flow is calculated using a two-dimensional structured mesh with roughly 66,000 grids and 60,000 nodes for the normal aerofoil domain. While, 750,000 grids and 70,000 nodes for the slotted aerofoil domain, as shown in Figures 4 and 5. A previous grid independency test validates the current grid sprints. The aerofoil's lift coefficient values at an angle of attack of 15° are displayed in Table 1. The table displays the values of C_L compared to a case study data by Beyhaghi and Amano [5,6] and the current data at 6^o angle of attack. It is evident from the table that there is a good coincidence between the results.

Table. 1 Independent case study results.

Run	Number of grids	Experimental C_L [5,6]	CFD C_L
1	40000	0.415	0.526
2	45000		0.426
3	65000		0.4211
4	75000		0.421

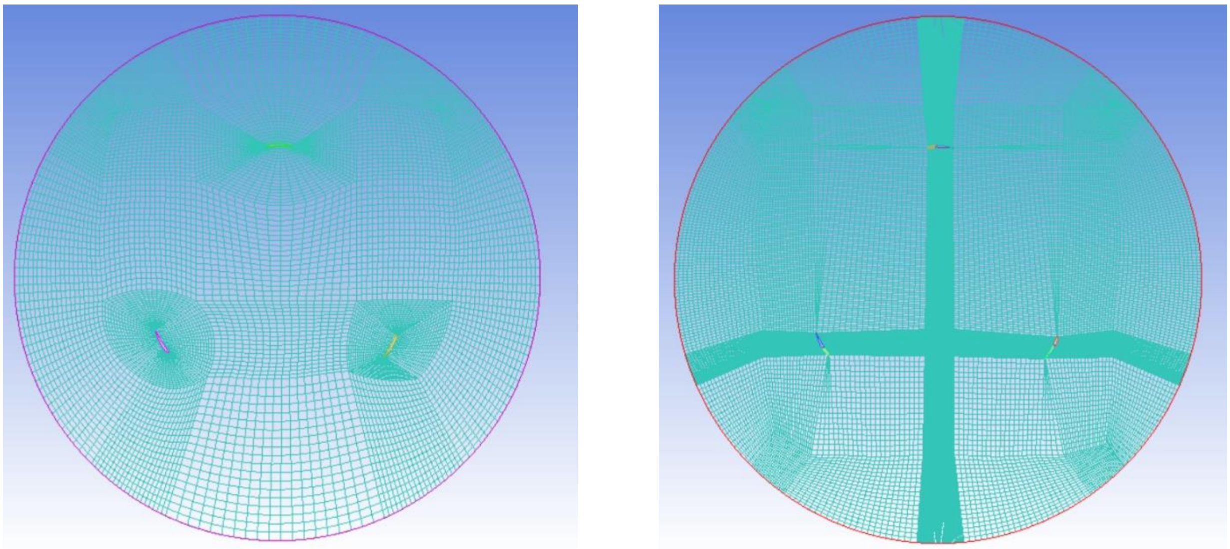


Fig. 4 Domain mesh of the two models, with slot on right and without on left.

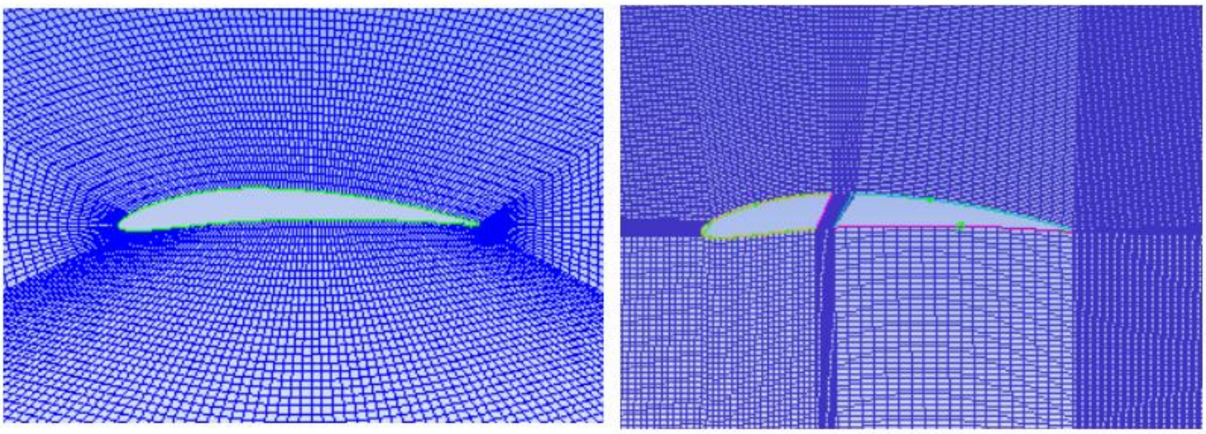


Fig. 5 Grid mesh of the two models, with slot on right and without on left.

2.3 Aerodynamics Calculations

2.3.1 Mathematical model

The flow on the current model was run according to the continuity and momentum equations with assumptions suit to the current two-dimensional, incompressible wind flow study [14], as follows:

$$\partial\rho/\partial t + \partial u/\partial x + \partial v/\partial y = 0 \quad (1)$$

$$\partial u/\partial t + \partial u^2/\partial x + \partial(uv)/\partial y = -\partial p/\partial x + [\partial^2 u/\partial x^2 + \partial^2 u/\partial y^2]/Re \quad (2)$$

$$\partial v/\partial t + \partial(uv)/\partial x + \partial v^2/\partial y = -\partial p/\partial y + [\partial^2 v/\partial x^2 + \partial^2 v/\partial y^2]/Re \quad (3)$$

The Reynolds number is a ratio of inertial to the viscose force, it is known in math form as:

$$Re = V\,c\,\rho/\mu \quad (4)$$

Where μ is the dynamic viscosity of air at a room temperature in Ns/m.

Equation (1) represents the continuity equation as flow transfers from the inlet to the outlet of the domain. While, equation (2) refers to the components of the velocity in the two-dimension domain.

2.3.2 Lift and drag coefficient calculations

After mesh was performed, the 2D vertical wind turbine was left to rotate according to the wind flow. The current model was obliged to rotate 2 rad/s to generate a lift force. The lift is a force that being upright to the direction of the wind flow [15] and is the force used to overcome gravity [16]. It develops as a result of unbalanced pressure on the upper and the undersides of the aerofoils. Whereas, the force of drag is due to uneven surface friction forces at the aerofoil as well as viscous friction forces pressure acting both towards and away from the approaching aerofoil surfaces stream. The force needed to defy gravity is called lift, and the greater the lift, the greater the mass that is hoisted off the earth. The two forces coefficients C_L and C_D are defined as follows:

$$C_L = \text{Lift force}/0.5\,\rho V^2 c \quad (5)$$

$$C_D = \text{Drag force}/0.5\,\rho V^2 c \quad (6)$$

Where ρ is the density of air at a room temperature in kg/m^3, and c is the length of the aerofoil from the tip to tail, often denoted by the term (chord).

In this study, the wind speed V ranges (4,6,10, and 15) m/s. In the attached flow regime, lift rises with angle of attack because flow is regarded at the aerofoil's upper surface. When developing in a high lift regime, the lift coefficient peaks when the aerofoil gets more and more stuck. There is stalling when the angle surpasses a particular threshold (based on the Reynolds number) and the upper surface undergoes boundary layer separation. The behaviour of aerofoils: aerodynamic performances are distinct due to the aerofoil's varied geometry.

The interval of time between a simulation's updates, or iterations, is called the time step. Selecting a suitable time step is crucial for maintaining the simulation's accuracy and stability [17].

2.3.3 Numerical validation

Because of lack in experimental works according to the current subject, the current mesh was validated with an experimental data performed by [18], as shown in Figure 6.

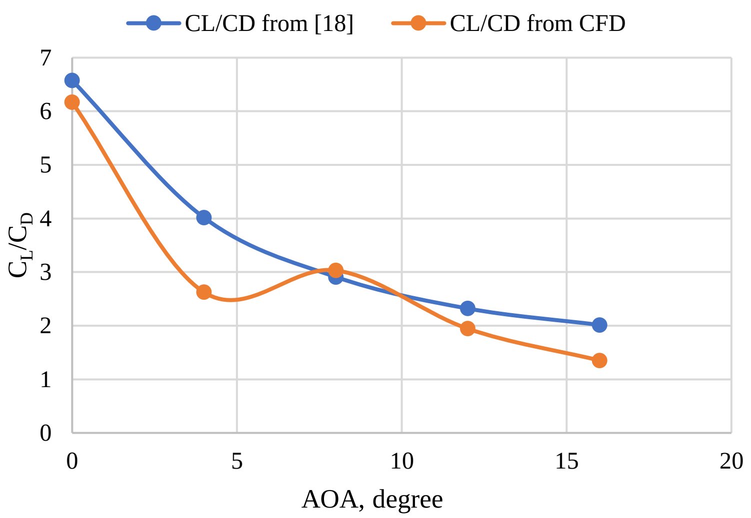


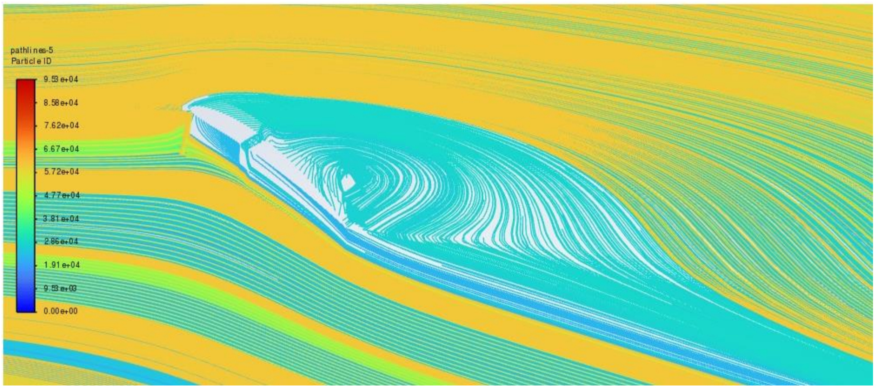
Fig. 6 Variation of lift to drag coefficients with AOAs.

The previous experimental work examined the aerodynamics of the normal shape of NACA4412 aerofoil at various AOA. Figure 6 illustrates that the curve of the lift to drag coefficient data in the experimental work is highly matching the current CFD work. Therefore, the current CFD mesh can be employed to run the main goal of the current work.

3. RESULTS AND DISCUSSIONS

3.1 Effect of the slot

As mentioned previously, the slot has played an important role in improvement the performance of aerfoils. In the current study, a numerical simulation was performed to display the behaviour of asymmetric aerofoils in a vertical wind turbine with existence of the slot. Numerical simulation of the flow around the circular includes slotted aerofoils is done using non-commercial ANSYS FLUENT 21.0 and turbulence model k-ω SST [17]. The influence of the slot may be seen when compared with the case without slot at different time step and various Reynolds number, as shown in Figure 7.



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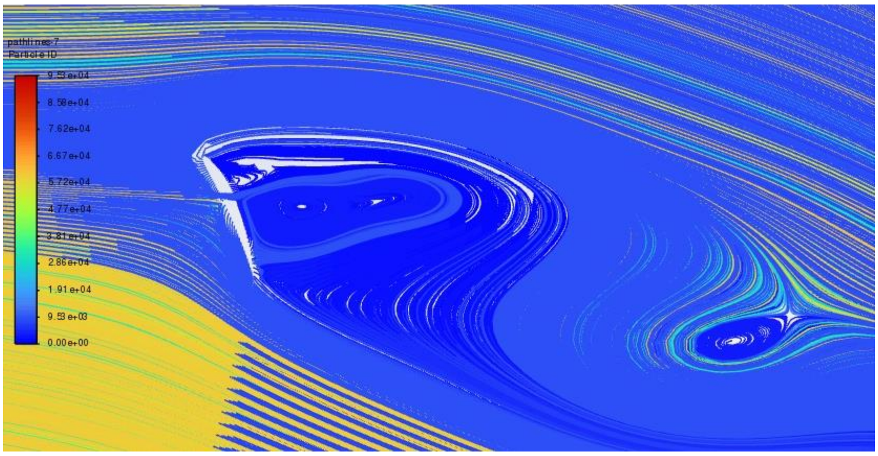

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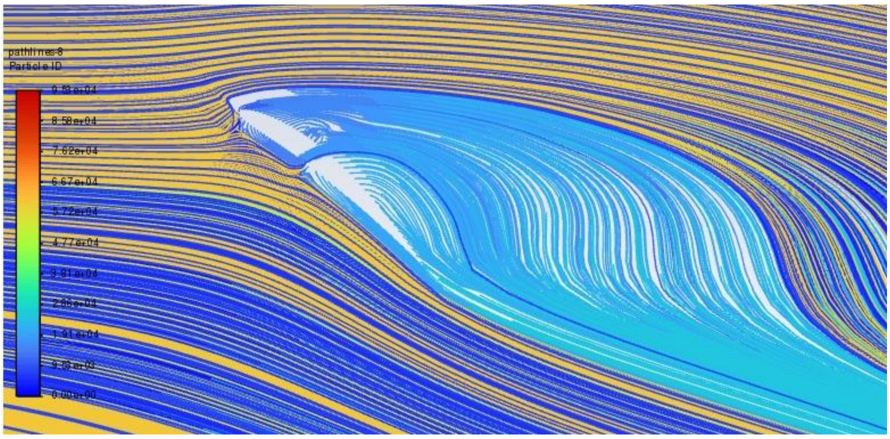
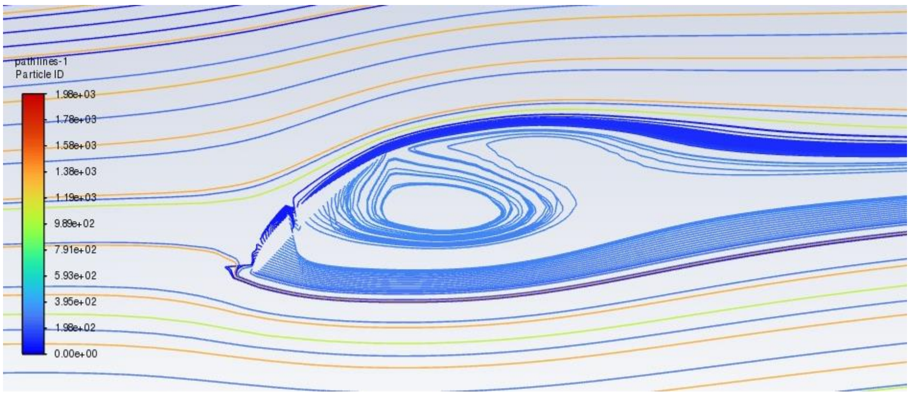


(c)

Fig. 7 Flow over the aerofoil at Re= 250000 and (a)500, (b) 1000 and (c) 2000 time step, with slot.

Figure 8, declares that the aerofoil can effectively provide enough momentum to flow above with slots. The extra momentum can enforce the boundary layer above the surface. That could support the flow and delay the separation of flow to near the trailing edge. The behaviour of the aerofoil can be noticeable at high time step.

For high Reynolds number 990000, the behaviour of the aerofoil is shown in Figure 7. It can be seen that the effect of the slot on the attached flow is clear. This is due to the extra flow that passes through slots that adds more momentum to flow above the aerofoils.



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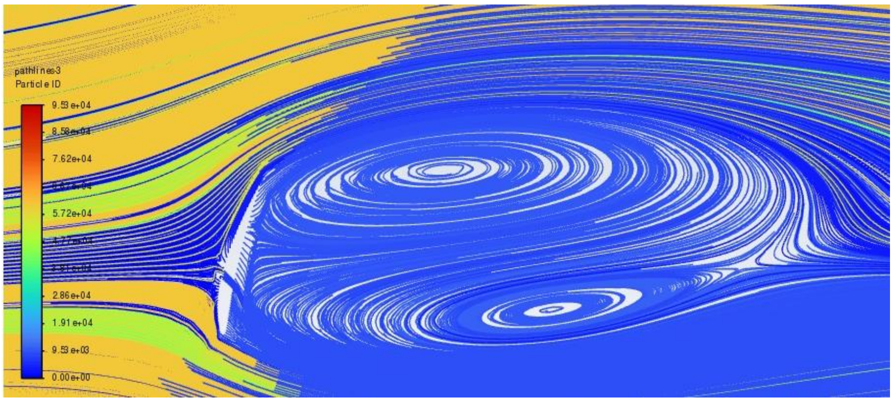

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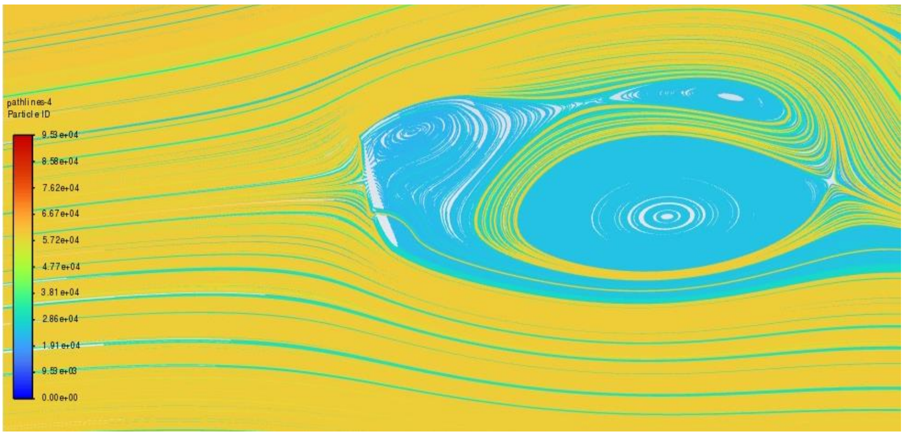
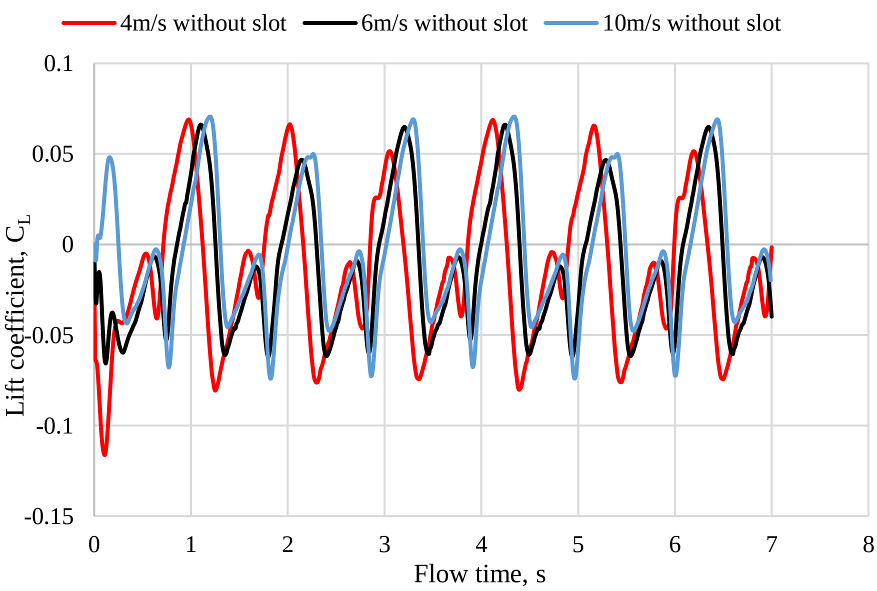
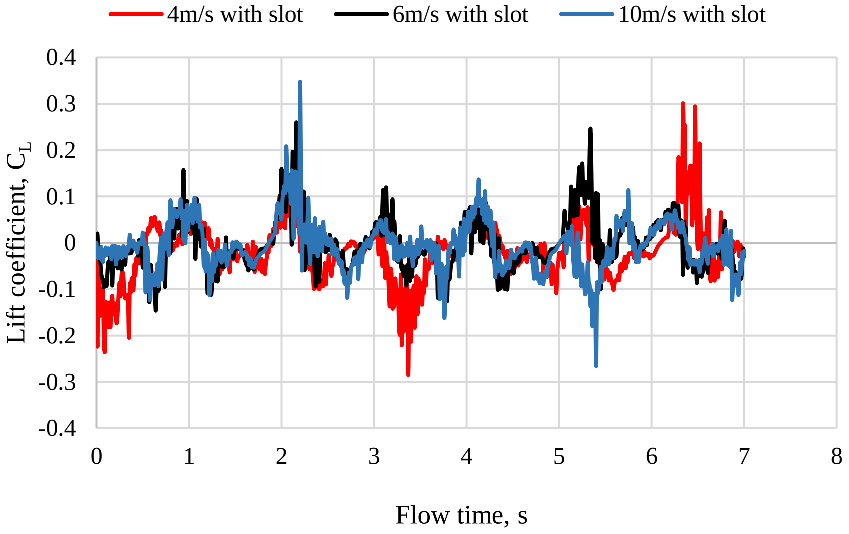


Fig. 8 Flow over the aerofoil at Re= 990000 and (a)500, (b) 1000 and (c) 2000 number of time step, with slot.



(a)



(b)

Fig. 9 Lift force values at three various Re,(a) without slot and (b) with slot.

Figure 9 (a) declares that the slotted aerofoils shapes in overall can generate lift force higher than that from the normal shapes. That may support almost views from previous studies. Moreover, the increase in Re can lead to produce more lift in slotted aerofoils. Whereas, in the normal case, the difference in Re appears has no high effect, as shown in Figure 8 (b).

3.2 Effect of vibrating aerofoils

The effect of the slot on rotating aerofoils when they vibrating due to wind flow and stiffness in their materials, was investigated in FLUENT using a UDF file. The UDF file, which is implied in FLUENT, is used to simulate the aerofoils vibration. The harmonic motion (cross flow) was utilized according to the following equation [14]:

$$y(t) = A_m \sin(2\pi f t) \qquad (7)$$

Where y(t) is the domain motion in the cross-flow, A_m is the vibration amplitudes of the vibrating domain, and t is the flow time in second. The harmonic motion was run using the dynamic mesh approach, which is a technique that can simulate the movement of solid objects in fluid domains. Figure 10 displays the behaviour of the slotted and normal aerofoils when the domain around the aeroifoils is vibrating. The results were gained at about 12.6 s from the start of the calculation, when the line of C_L started to be in a fluctuated shape.

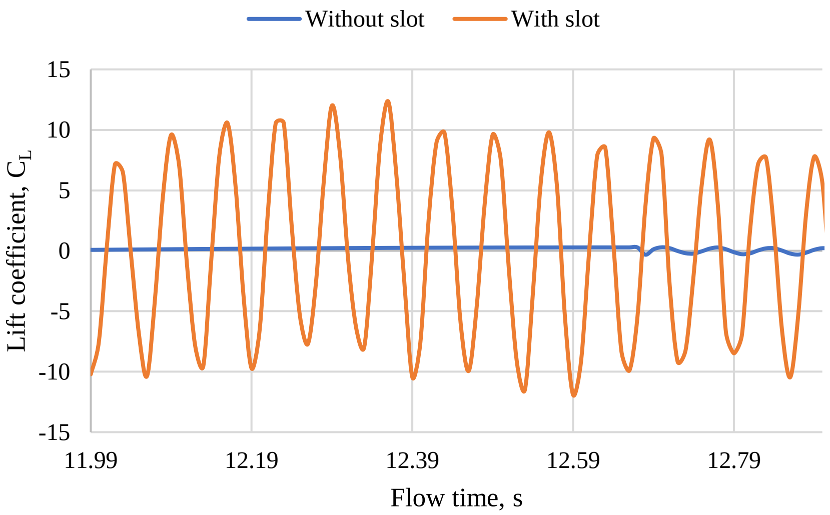


Fig. 10 Lift force values for 1Hz frequency.

In addition, Figure 11 shows that the aerodynamics of the slotted aerofoils would be dependent on the value of the Reynolds number. When the aerofoils are vibrating, the lift and drag C_L/C_D ratio increasing according to the increase in Reynolds number specially with the existence of the slot. Furthermore, the slotted aerofoil outperformed the normal ones about 10% except that at the high wind flow10m/s. The results of wind flow 15m/s were dropped due to the fluctuation in values at that high wind flow.

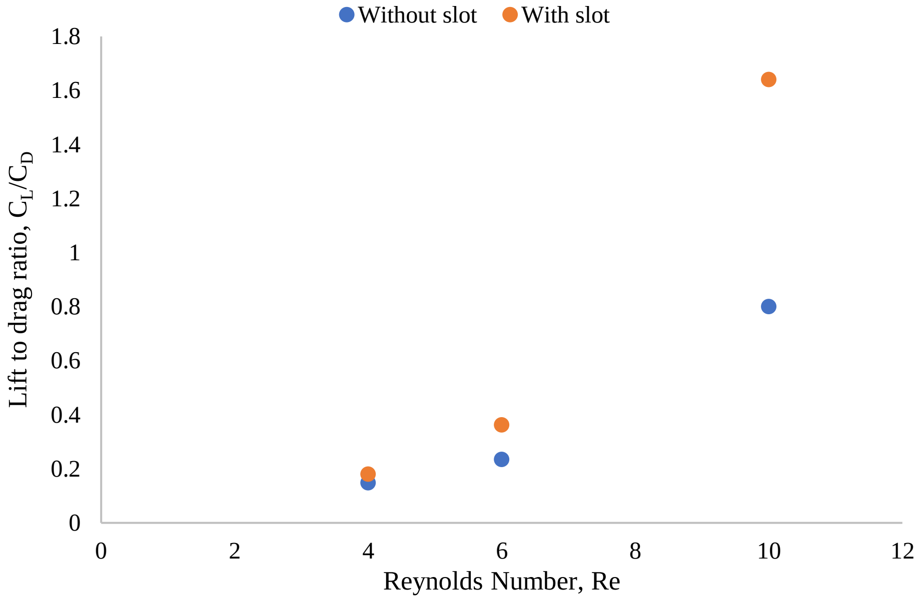


Fig. 11 Plot of lift to drag ratio versus Reynolds number.

4. CONCLUSION

The slotted and vibrating aerofoils were numerically investigated at various Reynolds numbers and numbers of flow time using an asymmetric NACA4412. Moreover, by comparing the two geometries, the slotted asymmetric aerofoils of the rotating turbine gave better behaviour against flow separation on above surface of aerofoils when compared to the normal aerofoils. Additionally, the aerodynamics of the NACA4412 aerofoils was validated. The lift to drag ratios showed highly agreement to that resulting from an experimental data. At 1Hz frequency of the motion of the aerofoils, the slotted aerofoils demonstrated 10% more aerodynamics than the normal shape aerofoils when increasing the Reynolds number value. For future work, the aerodynamics of a three-dimensional slotted wing of the NACA4412 aerofoil can be conducted under an unsteady wind flow.

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