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Effect of the J-shaped Airfoil Opening Ratio on the Performance of Symmetrical Airfoils

Saif Al Hamad, Omar Habash, Prof. Ryoichi Amano
Mechanical Engineering Department

Objectives

- Wind is a promising renewable energy solution since the output power from wind is directly proportional to the 3rd power of the wind velocity. And it is available during the night in contrast to solar energy. Among other renewable energies, the LCOE for wind energy solutions is one of the lowest for large scale projects
- There are 3 classifications for wind energy converters, horizontal axis converters, vertical axis converters, and up-stream converters
- The aim of this project is to study the performance of different J-shaped straight airfoil designs. The airfoil with the best performance could be then used to construct a Darrieus H-type vertical axis wind turbine
- Introducing openings will enhance the starting torque of H-type Darrius VAWTs by reducing the inertia of the turbine
- This way, the self-starting capability of the H-type Darrius VAWTs which are not normally self-start will be enhanced significantly

Approach

- The J profiled blades are formed by removing a portion of the blade starting from the trailing edge either from the pressure side or suction side of the conventional airfoil
- The J profile is defined by the cut or opening ratio, which is the ratio between the cut length to the chord length. The objective of introducing such an opening is to enhance the starting torque and power generation at low wind speeds using H-type Darrieus VAWT
- In this work, the effect of three inner opening ratios “1/3, 1/2, & 2/3” in J-shaped airfoils and their relationship with airfoil thickness was studied for symmetrical airfoils
- Furthermore, the performance of airfoils equipped with inner opening ratios was compared with the performance of their solid corresponded airfoils
- Proposed symmetrical airfoils are: NACA 0008, NACA 0015, and NACA 0024

Validation

- Experimental setup in the UWM-wind tunnel using NACA4412 airfoil, 15 m/s airflow, and for different angles of attack was used to validate the simulation data generated from the STAR CCM+ CFD software. The same experiment with the same specifications was simulated using STAR CCM+ software. Experimental and simulation results showed a very good agreement as shown in the Figure 1-a
- Another validation against published experimental data was performed. “Wadcock, A. J., 1978, “Flying-Hot-Wire Study of Two-Dimensional Turbulent Separation on an NACA 4412 Airfoil at Maximum Lift,” Ph.D. thesis, California Institute of Technology, Pasadena, CA ”. Validation results showed a good behavioral agreement as shown in the Figure 1-b
- Based on the mentioned two validation case studies, the CFD formulation can predict the performance of the proposed airfoil designs

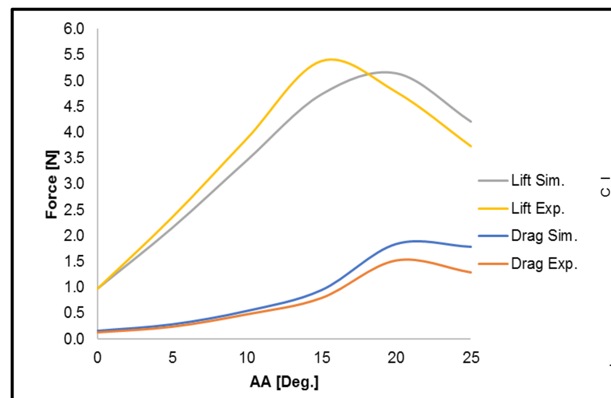
Figure 1-a: validation against UWM experimental data

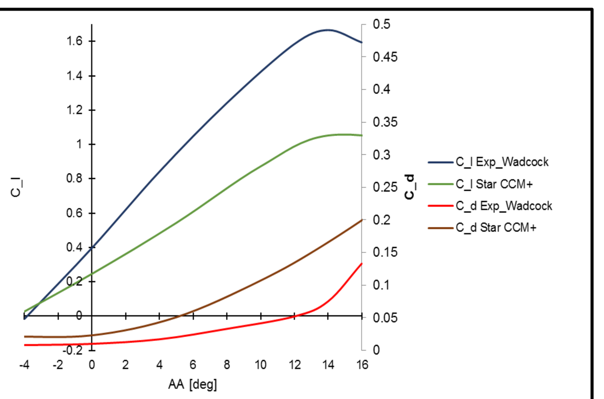
Figure 1-b: validation against published experimental data

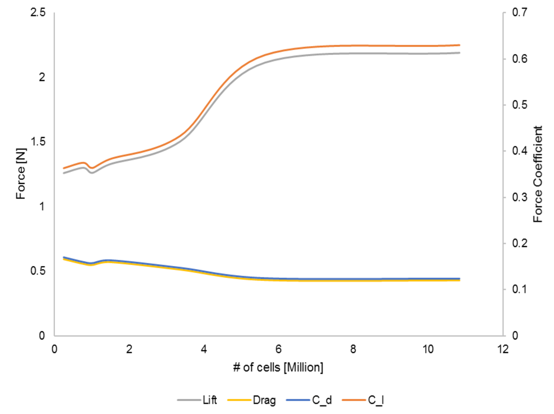
Figure 2: mesh independence study

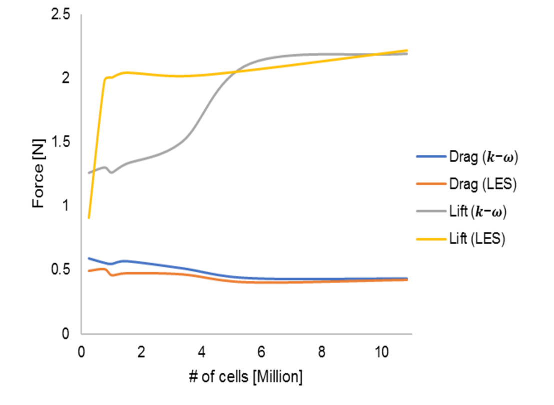
Figure 3: LES vs. k-ω turbulence model

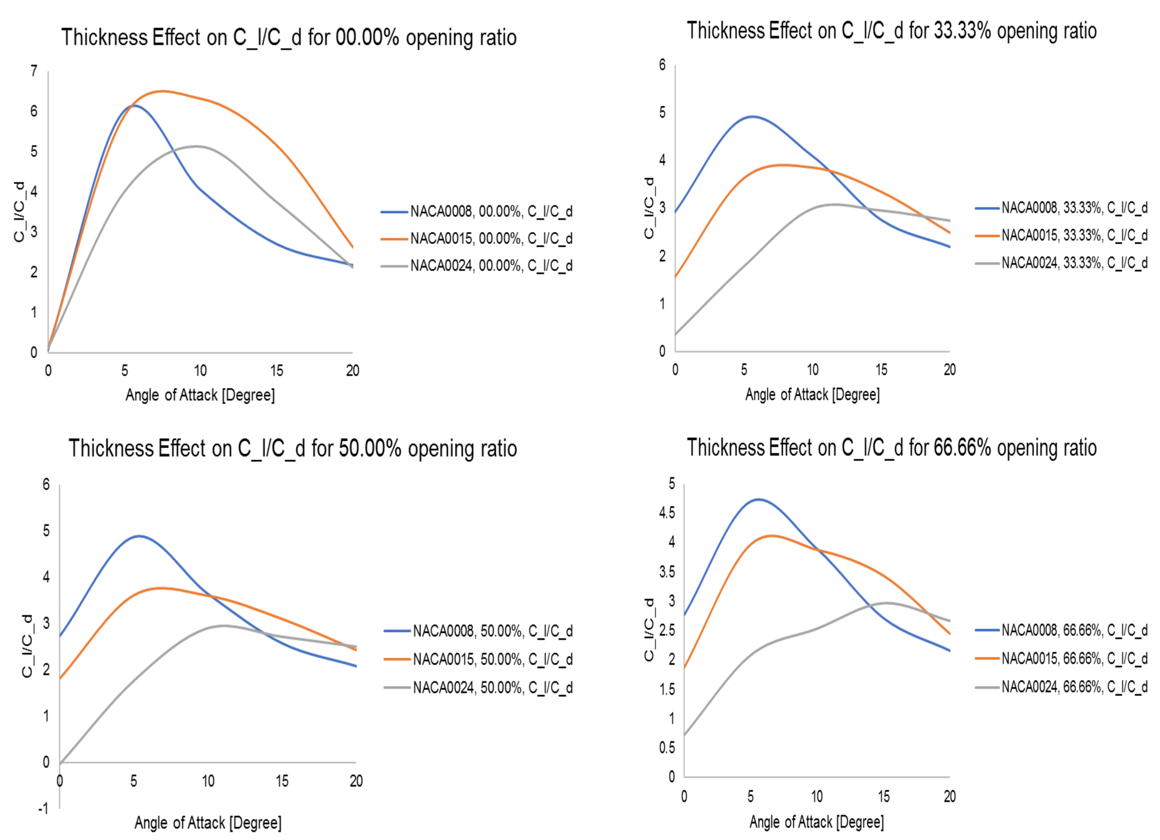
Figure 4: Effect of airfoil thickness

Mesh and Physics

- Before simulating the studied cases, a mesh independence study using NACA 0015 airfoil with a 0% opening ratio subjected to a stream of 15 m/s velocity magnitude and 0 angle of attack was carried out to determine the most reasonable mesh size.
- Mesh size was varied between 0.25 M to 11 M cells. Lift coefficient, drag coefficient, lift force, and drag force were evaluated for each run. Surface remesher with trimmer mesh, 10 prism layers of 10% thickness, volumetric controls of finer mesh around the airfoil with size of 10% of the base size, 10 prism layers of 10% thickness were used
- Physics: 3-D, steady, segregated flow, constant density, turbulent flow, $k-\omega$
- Figure 2 illustrates the mesh independence study results. Values start to be steadier with less error for a larger number of cells. It was decided to stick with a mesh size of around 6 million cells throughout this project
- The effect of using Large Eddy Simulation instead of k-ω turbulence model was investigated. Results of LES turbulence model were very close to the results of k-ω turbulence model as shown from figure 3
- Since our study is steady-state and does not contain any moving parts, it was decided to use the k-ω turbulence model for all further simulations

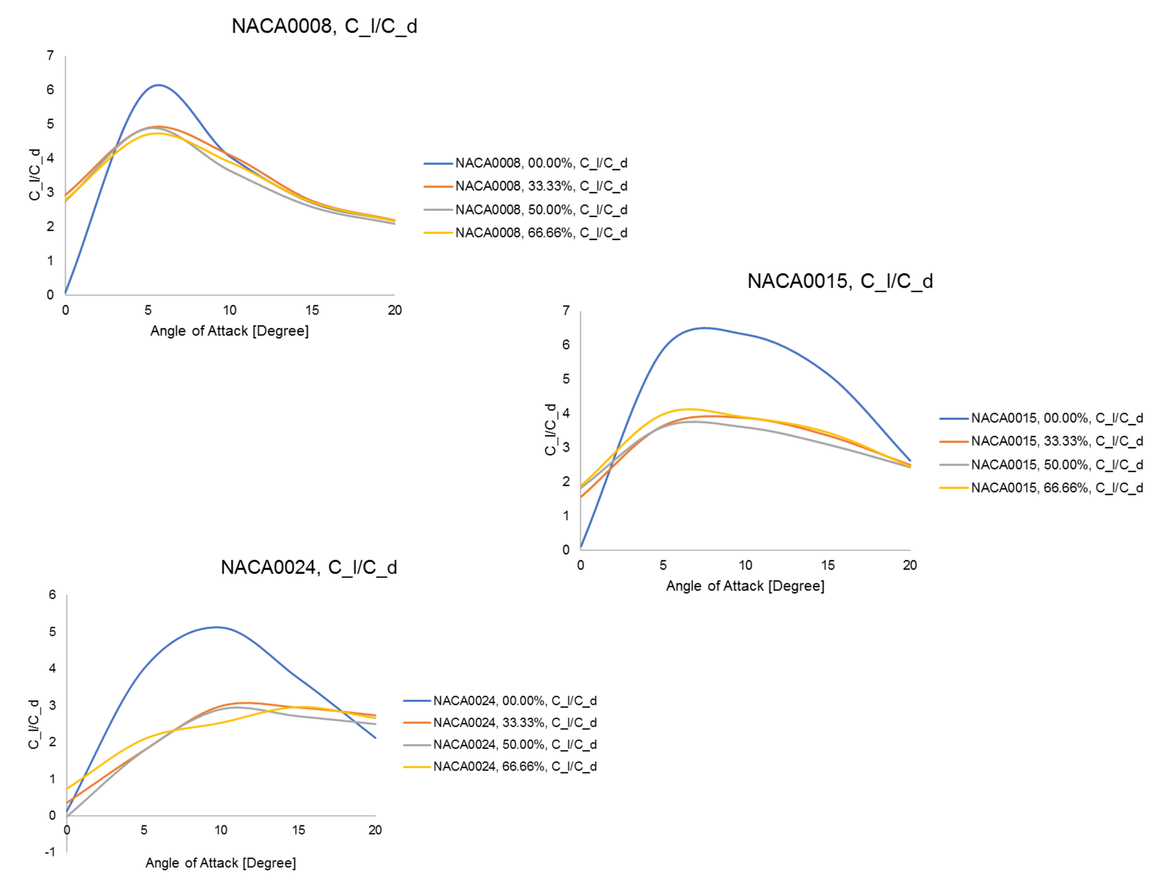
Figure 5: Effect of airfoil opening ratio

Results

- A total of 60 simulation runs for the proposed designs for different angles of attack were performed
- Figure 4 demonstrates the effect of airfoil thickness and opening ratio on the performance of each studied airfoil in terms of lift to drag ratio “Cl/Cd”. For airfoils equipped with 00.00% opening ratio, 15% thickness airfoil has the maximum Cl/Cd, for airfoils equipped 33.33% opening ratio, 8% thickness airfoil has the maximum Cl/Cd, for airfoils equipped 50.00% opening ratio, 8% thickness airfoil has the maximum Cl/Cd, and for airfoils equipped 66.66% opening ratio, 8% thickness airfoil has the maximum Cl/Cd.
- Figure 5 demonstrates the effect of the opening ratio on the performance of each studied airfoil in terms of lift to drag ratio “Cl/Cd”. For NACA008 equipped with openings, the one with 33.33% opening ratio has the maximum Cl/Cd, for NACA015 equipped with openings, the one with 66.66% opening ratio has the maximum Cl/Cd, and for NACA024 equipped with openings, the one with 33.33% opening ratio has the maximum Cl/Cd

Conclusions

- **Mesh quality affects the simulation results significantly and mesh independence study should always be implemented**
- **For the studied cases, it was found that it is not worthy to use unsteady Large Eddy Simulation instead of steady $k-\omega$ turbulence model**
- **Large Eddy Simulation yields accurate solutions with a smaller number of mesh cells compared to $k-\omega$ turbulence model but using more computational time**
- **The Cl/Cd ratio for all studied airfoils has a maximum value for solid airfoils when compared to their corresponding once equipped with openings**
- **Between all studied J-shaped airfoils, NACA0008 equipped with a 33.33% opening ratio seems to have the best performance.**
- **In future work, H-type Darrius VAWT using this J-shaped airfoil will be 3-D printed and compared with other VAWTs in terms of starting torque and power output**