Leading Edge Slot Configuration Effect on the Performance of Cambered Airfoils

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Introduction

• Since the output power from wind is directly proportional to the 3rd power of the wind velocity, it represents a promising renewable energy solution
• There are 3 classifications for wind energy converters, horizontal axis converters, vertical axis converters, and upstream converters
• Large scale wind energy is a proven energy solution while residential-scale wind turbines are still not proven and there is still room to work on enhancing their performance
• This project aims to study the effect of different leading-edge slot configurations on the aerodynamic performance of cambered airfoils
• The performance of slotted airfoils was investigated in terms of lift coefficient, drag coefficient, and lift to drag ratio
• The performance of the studied designs was numerically investigated using air flow at ambient temperature (21 °C) with 15 m/s speed and zero angle of attack

Approach

• The flow of air with ambient temperature ~70°F and constant velocity magnitude ~15 m/s over four proposed designs of NACA4412 with zero angle of attack airfoil was simulated and studied using Star CCM+ CFD software package
• Proposed designs were first modeled using the PTC Creo software, then imported into the Star CCM+ CFD software
• Lift forces, drag forces, lift coefficients, and drag coefficients were evaluated and compared for airfoils equipped with leading-edge slots
• Furthermore, the performance of airfoils equipped with leading-edge slots was compared with the performance of their solid corresponded airfoil
• The four proposed designs of NACA4412 airfoil are: solid, slotted, slotted diverging, and slotted converging airfoils

Validation

• The aerodynamic performance of solid NACA4412 airfoil of 7 chord length and 10 in span was investigated experimentally in the UWM wind tunnel facility using 15 m/s air flow and different angles of attack between 0 degree and 25 degrees by a step of 5 degrees, this test was used to validate the CFD results
• The same experiment with the same specifications was simulated using STAR CCM+ software
• Dimensions of the wind tunnel test section were used in the simulation (1.2 m x 1.2 m x 2.4 m)
• Experimental and simulation results showed a very good agreement as shown in the Figure 1 and Figure 2
• Based on the mentioned validation case study, the CFD formulation can predict the performance of the proposed airfoil designs

Figure 1: Validation against UWM experimental lift and drag forces

Mesh and Physics

• A mesh independence study was carried out in a previous publication to decide the most reasonable mesh size for the used domain dimensions
• It was found that for cell count beyond 6 M, simulations yield relatively constant values for the generated lift and drag
• For this study, number of cells was maintained around 8 M cells for the studied four cases
• Table 1 lists the boundary conditions used for all studied cases

Table 1: Boundary conditions

<table>
<thead>
<tr>
<th>Inlet Air Velocity</th>
<th>Local Reynolds Number</th>
<th>Global Reynolds Number</th>
<th>Outlet Pressure</th>
<th>Walls</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 m/s</td>
<td>2 x 10^6</td>
<td>1.2 x 10^6</td>
<td>Atmospheric (101.325 kPa)</td>
<td>Non-slip condition</td>
</tr>
</tbody>
</table>

• Mesh: surface remesh with trimmer mesh and with prism layers (5 prism layers with 1.5 growth rate). The base size was set to 25 mm, with volumetric controls of finer mesh with 2.5 mm for the airflow and the region downstream of length of 6 cord lengths
• Mesh scene for solid NACA4412 is shown in Figure 3
• Physics: 3-D, implicit unsteady, segregated flow, constant density, and turbulent flow using k-ω turbulence model with gamma transition

Figure 2: Validation against UWM experimental lift to drag ratio

Figure 3: Solid NACA4412 mesh scene

Results

• Simulations were performed for the studied designs. Reports for lift forces, drag forces, lift coefficients, and drag coefficients were generated. A comparison between them is presented in Table 2

Table 1: Aerodynamic performance results for studied cases

<table>
<thead>
<tr>
<th>Airfoil</th>
<th>Slotted</th>
<th>Diverging</th>
<th>Converging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lift Coef.</td>
<td>0.8152</td>
<td>1.0598</td>
<td>1.1453</td>
</tr>
<tr>
<td>Lift Force</td>
<td>0.6564</td>
<td>0.7313</td>
<td>0.7086</td>
</tr>
<tr>
<td>Drag Coef.</td>
<td>0.1819</td>
<td>0.2584</td>
<td>0.3092</td>
</tr>
<tr>
<td>Drag Force</td>
<td>0.1461</td>
<td>0.1784</td>
<td>0.2134</td>
</tr>
<tr>
<td>Lift/Drag</td>
<td>4.4816</td>
<td>4.1007</td>
<td>3.7043</td>
</tr>
<tr>
<td>Diff</td>
<td>4.3630</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions

• The slotted diverging profile has the maximum lift, on the other hand, it yielded maximum drag among other profiles, however, it has the minimum lift to drag ratio
• The solid profile has the maximum lift and the minimum drag among other profiles, however, it has the maximum lift to drag ratio
• The slotted profile yielded a maximum lift to drag ratio
• The slotted converging profile yielded a comparable lift to drag ratio with the solid profile
• In future work, proposed profiles will be studied under different angles of attack and the effect of angle of attack is to be investigated. Furthermore, the ability to use such designs in commercial wind turbines is to be investigated

Appendix

• Proposed designs dimensions are shown in Figure 4. Dimensions are decided based on a previous publication by the UWM wind tunnel facility
• For the slotted profile, slot width was set to 2% of the cord length “6 mm”, first leg length was set to 80% of the cord length “48 mm”, slot angle of 4 degrees, second leg angle of 25 degrees, and the outlet width of 3.48 mm
• For the slotted diverging profile, slot width was set to 2% of the cord length “6 mm”, first leg length was set to 80% of the cord length “48 mm”, slot angle of 4 degrees, second leg angle of 25 degrees, and the outlet width of 4.36 mm of slotted profile “53.65 mm”
• For the slotted converging profile, slot width was set to 2% of the cord length “6 mm”, first leg length was set to 80% of the cord length “48 mm”, slot angle of 4 degrees, second leg angle of 25 degrees, and the outlet width of 0.25 outlet width of slotted profile “53.65 mm”

Figure 4: Proposed designs dimensions