Simulating the Aerodynamics Profiles of NACA 4312 Airfoil in Various Incoming Airspeed and Gurney Flap Angle

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Abstract
Simulations of the aerodynamics performance of NACA 4312 airfoil at various gurney flap angles and incoming airspeed (wind velocities) have been conducted. The gurney flap’s size was set at 5.0% length of the chord line. Two airfoil models with gurney flap at 45° and 90° were simulated and compared with the results of plain airfoil (without gurney flap) model with the incoming airspeed of 10.0 m/s, 70.0 m/s and 200.0 m/s. The results have shown that increasing the value of gurney flap angle to 45° and 90° will increase the lifting force of the airfoil and decrease the drag force.

Introduction
Understanding the behavior of air flow around a moving body is really important as we can manipulate those air flow for our benefit such as in the case of airplane, wind turbine, drone and many more. Aerodynamics as a branch of physics focuses on studying that phenomena by using basic physics laws like Newton’s laws and Navier Stokes equation. To study the aerodynamics profile of a particular object one needs to define the shape of the object, where in the case of airplane is the airfoil or the cross section of the wing. The aerodynamics profile of an airfoil can be investigated by two means, experimentally and computationally. In the experimental approach, the aerodynamics profiles of an airfoil are obtained by putting the airfoil (or wing model) in a controlled wind tunnel and record the velocity and pressure distribution around the airfoil. In the computational approach the same experiment can be done in the computer using for instance, a Computational Fluid Dynamics (CFD) simulation. Both approach usually are compliment with each other and can help us in designing the airfoil with a specific purpose.

One particular source of the airfoil model is the NACA database [1]. NACA which stands for National Advisory Committee for Aeronautics offers a numerous airfoil models which can be used or tested in a CFD simulation. In this paper we would also add a gurney flap, a small tab attached at the rear of the airfoil. Historically a gurney flap was popularized by Dan Gurney, an American racer who tried to increase the performance of his racing car by using a small tab at his cars spoiler [2]. By putting such a tab, Dan Gurney was able to increase the downforce on his car which made his car more stable on the track especially around the bend.

Studying the aerodynamics performance of a particular object can be done in two ways, exper-
mentally or computationally. In the experimental approach, the object models were isolated in the wind tunnel and tested with various conditions (incoming wind speed, air density, temperature, etc). The velocity and pressure around the object vicinity were measured and recorded to visualize the aerodynamics profiles of the object. In the simulation approach the data of velocity and pressure were generated by physical laws such as Navier-Stokes equation, Bernoulli equation, and Coanda’s effect [3,4]. This CFD (Computational Fluid Dynamics) simulation such as Autodesk CFD have been widely used for aerodynamics modeling with a high degree of satisfaction.

In this paper we will simulate the aerodynamics performance of NACA4312 airfoil with and without a gurney flap at various incoming airspeed. The gurney flap angles will be set at 45° and 90°, while the velocity of incoming airspeed set at low (10.0 m/s), medium (70.0 m/s), and high (200.0 m/s). Design of Airfoil and NACA 4312 were done using Autodesk Inventor, while the aerodynamics modelings were done using Autodesk CFD.

Methods

The NACA airfoil series are denoted by four numbers code, like in this case NACA 4312. The first number (which is 4) denotes the percentage of chamber to chord (the chamber length is 4% of the chord line). The second number (which is 3) indicates the decimal ratio of the location of maximum chamber in term of chord line. The last two digits (which is 12) indicate the percentage of the airfoil thickness as compared to the length of the chord line.

Results and Discussion

The simulation of aerodynamics profiles of NACA 4312 airfoil were done using AutoDesk CFD. The contour plot of velocity and pressure distribution around the airfoils were obtained for each variation of incoming airspeed. The attacking angle of the airfoils were set to zero since we only interested in studying the effect of gurney flap on various incoming airspeeds. Similar study with a different type of NACA airfoil has been done by Ref [5,6].

The aerodynamics profiles of the NACA 4312 were shown in terms of velocity distribution and pressure distribution around the airfoil in three conditions low, medium and high airspeed. There are three models of NACA 4312 airfoil tested in this simulation, a plain airfoil (without a gurney flap), airfoil with gurney flap at 45°, and airfoil with gurney flap at 90°.

The velocity distribution around a plain airfoil for low incoming airspeed (10.0 m/s) is shown in Figure 3(a), while the pressure distribution is shown in Figure 4(a). The air velocity in the upper side of airfoil were found around 6.0 to 12.5 m/s, while in the lower side around 3.0 to 7.0 m/s. The air pressure in the upper side were found around 101291 to 101310 Pa, while in the lower side around 101317 to 101330 Pa. Those aerodynamics profiles indicates a small lifting forces were obtained in that setup of simulation with the average pressure difference around 18 Pa.

For the medium incoming airspeed (70 m/s), the velocity distribution around a plain airfoil for low incoming airspeed (10.0 m/s) is shown in Figure 3(b), while the pressure distribution is shown in Figure 4(b). The air velocity in the upper side of airfoil were found around 6.0 to 12.5 m/s, while in the lower side around 3.0 to 7.0 m/s. The air pressure in the upper side were found around 101291 to 101310 Pa, while in the lower side around 101317 to 101330 Pa. Those aerodynamics profiles indicates a small lifting forces were obtained in that setup of simulation with the average pressure difference around 18 Pa.
around 99812 to 100700 Pa, while in the lower side were found around 101278 to 101492 Pa. A higher lifting pressure (or force) is obtained in this setup of simulation with the average pressure difference around 1129 Pa.

Figure 3: The contour plots of velocity distribution around a plain NACA 4312 airfoil for (a) a low incoming airspeed (10.0 m/s), (b) a medium incoming airspeed (70.0 m/s), and (c) a high incoming airspeed.

The velocity distribution around a plain airfoil for a high incoming airspeed (200.0 m/s) is shown in Figure 3(c), while the pressure distribution is shown in Figure 4(c). The air velocity in the upper side of airfoil were found around 100.0 to 245.0 m/s, while in the lower side around 79.0 to 225.0 m/s. The air pressure in the upper side were found around 88883 to 96345 Pa, while in the lower side around 97291 to 100759 Pa. Those aerodynamics profiles indicates a higher lifting pressure (or force) were obtained in that setup of simulation with the average pressure difference around 6411 Pa.

For the medium incoming airspeed (70 m/s), the velocity distribution around the 45° gurney flap angle NACA 4312 airfoil is shown in Figure 5(b), while the pressure distribution is shown in Figure 6(b). The air velocity in the upper side of airfoil were found around 10.0 to 11.7 m/s, while in the lower side around 8.0 to 10.5 m/s. The air pressure in the upper side were found around 99495 to 100585 Pa, while in the lower side were found around 101200 to 101370 Pa. A higher lifting pressure (or force) is obtained in this setup of simulation with the average pressure difference around 1245 Pa.

The drag pressure (force) is decreased as the incoming airspeed increased as seen in Figure 4(a), (b), and (c). The small blob in front of the airfoil refers to additional thrusting pressure (or force) due to the geometrical shape of the airfoil. As the incoming speed increased this blob becomes smaller but on the other hand the drag force around the airfoil also decreased. This result is in agreement with other researchers [7–9] where the increasing lift force is followed by a small drag penalty.

Figure 4: The contour plots of pressure distribution around a plain NACA 4312 airfoil for (a) a low incoming airspeed (10.0 m/s), (b) a medium incoming airspeed (70.0 m/s, and (c) a high incoming airspeed.
Figure 5: The contour plots of velocity distribution around the 45° gurney flap angle NACA 4312 airfoil for (a) a low incoming airspeed (10.0 m/s), (b) a medium incoming airspeed (70.0 m/s), and (c) a high incoming airspeed.

For the high incoming airspeed (200.0 m/s), the velocity distribution around the 45° gurney flap angle airfoil is shown in Figure 5(c), while the pressure distribution is shown in Figure 6(c). The air velocity in the upper side of airfoil were found around 194.0 to 240.0 m/s, while in the lower side were found around 134.0 to 217.0 m/s. The air pressure in the upper side were found around 87599 to 93553 Pa, while in the lower side were found around 102280 to 103280 Pa. A higher lifting pressure (or force) is obtained in this setup with average pressure difference around 12204 Pa.

Figure 6: The contour plots of pressure distribution around the 45° gurney flap angle NACA 4312 airfoil for (a) a low incoming airspeed (10.0 m/s), (b) a medium incoming airspeed (70.0 m/s), and (c) a high incoming airspeed.

The velocity distribution around the 90° gurney flap angle airfoil for a low incoming airspeed (10.0 m/s) is shown in Figure 7(a), while the pressure distribution is shown in Figure 8(a). The air velocity in the upper side of airfoil were found around 6.0 to 12.5 m/s, while in the lower side around 4.0 to 11.0 m/s. The air pressure in the upper side were found around 101283 to 101307 Pa, while in the lower side were found around 101335 to 101339 Pa. Those aerodynamics profiles indicates a small lifting force is obtained in that setup of simulation with average pressure difference around 42 Pa.

The velocity distribution around the 90° gurney flap angle airfoil for a medium incoming airspeed (70.0 m/s) is shown in Figure 7(b), while the pressure distribution is shown in Figure 8(b). The air velocity in the upper side of airfoil were found around 40.0 to 85.0 m/s, while in the lower side around 35.0 to 75.0 m/s. The air pressure in the upper side were found around 99400 to 100218 Pa, while in the lower side around 101942 to 102050 Pa. Those aerodynamics profiles indicates a moderate lifting force is obtained in that setup of simulation with the average pressure difference around 2187 Pa.

The velocity distribution around the 90° gurney flap angle airfoil for a high incoming airspeed (200.0 m/s) is shown in Figure 7(c), while the pressure distribution is shown in Figure 8(c). The air velocity in the upper side of airfoil were found around 100.0 to 245.0 m/s, while in the lower side around 82.0 to 216.0 m/s. The air pressure in the upper side were found around 86311 to 91235 Pa, while in the lower side around 102481 to 103997 Pa. Those aero-
The performance of the NACA 4312 airfoil in various incoming airspeed and gurney flap angle can be summarized in Figure 9. In general, the increasing gurney flap angle will increase the lifting force \( F = \Delta P A \); where \( \Delta P \) is the pressure difference between the lower and upper side of the airfoil, and \( A \) is the area of the wing) in low, medium and high incoming airspeed. The profile of medium airspeed performance of NACA 4312 is slightly different in Figure 9 as shown by a relatively constant of \( \log \Delta P \) between a plain airfoil and airfoil with 45° gurney flap angle (\( \log \Delta P = 3.05 \) for airfoil without gurney flap and \( \log \Delta P = 3.09 \) for airfoil with a 45° gurney flap angle). This result is in agreement with other researchers [7–9] where the increasing performance (lift force) of airfoil due to the addition of gurney flap is followed by a small drag force penalty.

Figure 7: The contour plots of velocity distribution around the 90° gurney flap angle NACA 4312 airfoil for (a) a low incoming airspeed (10.0 m/s), (b) a medium incoming airspeed (70.0 m/s, and (c) a high incoming airspeed.

Figure 8: The contour plots of pressure distribution around the 90° gurney flap angle NACA 4312 airfoil for (a) a low incoming airspeed (10.0 m/s), (b) a medium incoming airspeed (70.0 m/s, and (c) a high incoming airspeed.

Figure 9: The overall performance of NACA 4312 airfoil at various incoming airspeed and gurney flap angle. Note that the zero gurney flap angle in this figure corresponds to a plain NACA 4312 airfoil without a gurney flap.
Conclusion

We have simulated the performance of NACA 4312 airfoil at various incoming airspeed and gurney flap angles. The results have shown that increasing the value of gurney flap angle to 45° and 90° will increase the lifting force of the airfoil and decrease the drag force.

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