Research on Aspect Ratio and Angle of Attack for Optimizing the Performance Of Airfoil NACA 24112

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Abstract Airfoils produce lift force for aircrafts, and it is one of the most crucial components of the aircraft. For the purpose of better performance of the aircraft in the sky, it becomes important to design a suitable airfoil for sustaining a stable process of aviation. The overall objective of this very paper is to optimize the design of airfoil, specifically by exploring the effect of changing aspect ratio and angle of attack on aircraft performance, in a simplified case with certain initial conditions and boundary conditions that will be specified later. In order to realize the overall objective of this paper, the feature of flow simulation of Solidworks will be utilized to create a geometrical model and also run various computational fluid dynamics simulations (CFD), in company with python programming for numerical calculations to process various data. The original model of airfoil is the national advisory committee for aeronautics (NACA) 24112. As a consequence of the research and exploration process, it is discovered that under the condition of aspect ratio of 2 and angle of attack of 5°, the performance of airfoil NACA 24112 could be optimized with a lift force to drag force ratio of approximately 5.955.

Keywords Aircrafts · Suitable airfoil · Solidworks · Geometrical mode · Python programming

1 Introduction

Ever since the beginning of the information age, the advancement in technology and computer science has been made and facilitated as time passes by. In addition, various computational software is created and iterated to become more and more mature, with more efficient and accurate features generated. In the field of physics, engineering and aerospace industry, computational fluid dynamics (CFD), is one of the most popular and crucial subjects with various applications in real life situations,

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for its capability of producing quantitative predictions of fluid-flow for objects based on certain initial or boundary conditions [1]. In this paper, the software of Solidworks will be utilized for the purpose of airfoil modeling, and for the purpose of CFD modeling, the flow simulation feature of Solidworks will be utilized, to obtain crucial information about the performance of airfoil. In addition to the computational simulation results obtained by the solidworks software, python programming has also been utilized to conduct numerical calculations, for lift coefficient and the final plotting.

For aircraft design, the airfoil is a critical component of the whole aviation system. One of the most important functions of an airfoil is to generate enough lift force, for the purpose of taking off and also sustaining a stable flight. In addition, it is important to minimize the drag during the flight time, since drag forces would require more energy input for the airplane to consume. In addition, the geometry of the airfoil is also particularly crucial as it determines various aspects of the flight performance. The geometry of the airfoil has been selected as NACA 24112 and in this paper, a comprehensive aerodynamic study of the airfoil will be conducted, with the consideration of the angle of attack and the aspect ratio [2]. The general purpose is to obtain the optimization of conditions for NACA 24112 to function; the parameters that will be utilized to evaluate the performance of the airfoil will include but are not limited to lift coefficient, drag coefficient and lift force to drag force ratio. The overall objective of optimization would be to maximize the lift and maximize the lift to drag ratio.

Regarding the methodology of this paper, two general approaches will be utilized for evaluating the parameters. Firstly, a computational fluid dynamics analysis will be conducted, utilizing solidworks for modeling purposes and solidworks flow simulation. Besides, an analytical method by calculating the lift coefficient numerically by python programming will also be conducted. The results of those approaches will be analyzed in order to evaluate under which scenario the optimization of airfoil NACA 24112 could be obtained.

2 Methodology

2.1 Geometric Model Creation of NACA 24112

To create the geometric model of NACA 24112, the coordinates of NACA 24112, in the two-dimensional (2D) form need to be imported. In this case, the credit of the 2D coordinates shall be given to "airfoil database research", where the information regarding this NACA 24112 can be accessed [3]. The reasoning behind choosing NACA 24112 is because it is vertically unsymmetrical which would contribute to the creation of lift force. By utilizing the function of extrusion in solidworks, extruding the 2D face horizontally would create the final three-dimensional object of the NACA 24112, which is shown below in Fig. 1.

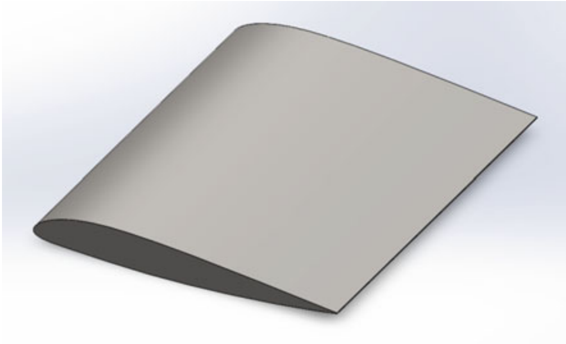


Fig. 1 Three-dimensional form of NACA 24112 airfoil

There are two crucial parameters that would influence the performance of NACA 24112 airfoil, which are the aspect ratio and the angle of attack. Aspect ratio is defined as the ratio between the wingspan and the chord length, where wingspan is the average width of the airfoil and the chord length is the length of the surface [4]. The aspect ratio can be changed by adjusting the amount of extrusion of the airfoil and for the purpose of exploring its influence on the lift and drag force generation, five aspect ratios have been selected, which are 1, 1.25, 1.50, 1.75 and 2.00. The following Fig. 2 offers an example of aspect ratio of 2.

Angle of attack is defined as the angle between the incoming air and a reference line of the wing, which is the chord line of the airfoil in this case [5]. The angle of attack can be changed by adjusting the rotation of the airfoil, whereas the feature of "Body-Move/Copy" has been utilized. Specifically, the rotation around the z-axis has been selected for 0, 5, 10, 15, 20° for the rotation (angle of attack); an example of angle of attack of 15° is demonstrated below in the Fig. 3. The reasoning behind choosing 20° as the highest value is because a too high angle of attack might make the airfoil detached, resulting in the loss of lift so the increment only increases upon 20°, in order to avoid loss in lift generation [6].

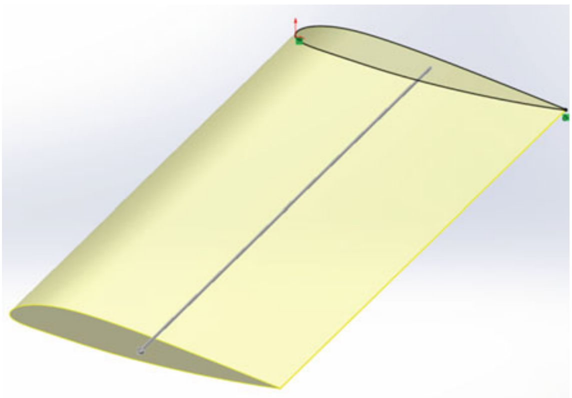


Fig. 2 Extrusion of NACA 24112 airfoil for aspect ratio of 2

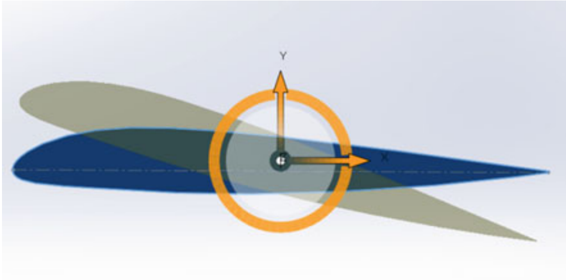


Fig. 3 Rotation of 24112 airfoil for angle of attack of 15°

Table 1 CFD simulation parameters

	Parameters	Value
1	Pressure	101325 Pa
2	Temperature	293.2 K
3	Fluid velocity	34.3 m/s
4	Airfoil	NACA 24112
5	Airfoil chord length	9.140 m

2.2 *Flow Simulation of NACA 24112 (Physical Model)*

After the three-dimensional NACA 24112 is constructed, the flow simulation could be run upon this model. It is important to firstly specify the initial conditions regarding various physical parameters. Here is the list of initial conditions, shown in the following Table 1.

As shown in Fig. 4, an example flow simulation results for 20° angle of attack and aspect ratio of 2 is shown; GG stands for global variable and “GG Force (X)” and “GG Force (Y)” correspond to the drag force and lift force, respectively. By repeating this flow simulation in a similar way to the other set of angle of attack and aspect ratio, the results of drag force and lift force could be obtained eventually and an analysis of them will be conducted in the results and discussion section of this paper [7].

2.3 *Mathematical Model*

The formula for calculating drag coefficient is expressed as the following:

$$C_d = \frac{2 * F_d}{\rho * v^2 * A_p} \tag{1}$$

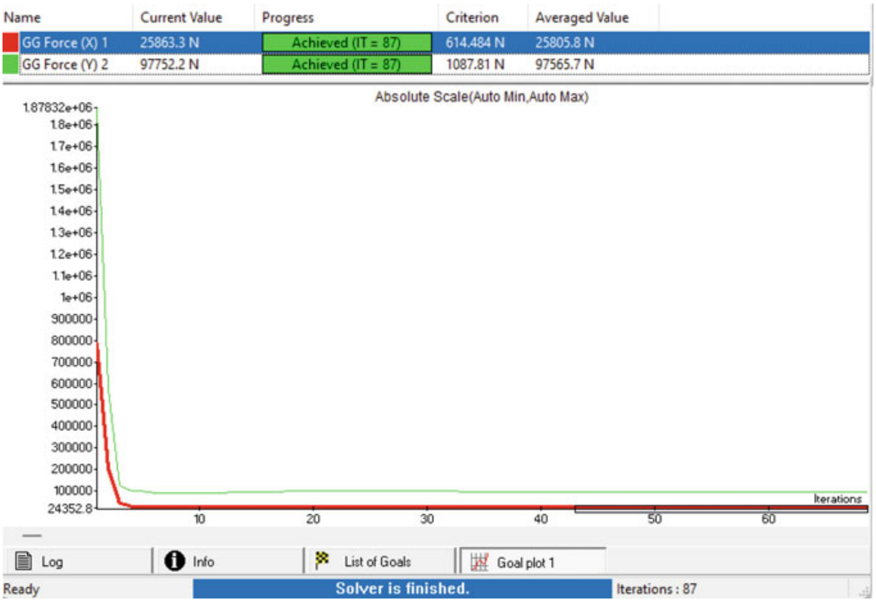


Fig. 4 Example flow simulation results for 20° angle of attack and aspect ratio of 2

where, F_d is the drag force; ρ is the density of the fluid, which is air in this case of 1.2004 kg $*$ m^3; v is the velocity of the fluid, which is set as 34.3 ms^{-1} for the initial condition; A_p is the planform area of the airfoil.

For planform area of the airfoil, it can be expressed as:

$$A_p = c * l = \mathrm{AR} * c^2 \tag{2}$$

where, C is the chord length of the airfoil, which is 9.140 m in this case; L is the wing span; AR is the aspect ratio that is defined as the ratio between wingspan to chord length.

Similarly, the formula for calculating lift coefficient is expressed as the following:

$$C_l = \frac{2 * F_l}{\rho * v^2 * A_F} \tag{3}$$

where, F_l is the lift force; A_F is the frontal area of the airfoil.

For frontal area of the airfoil, it can be expressed as:

$$A_p = t * l \tag{4}$$

where, T is the height of the airfoil, which is measured from the highest point to the lowest point of the airfoil vertically.

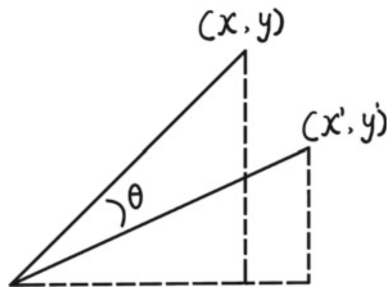


Fig. 5 Rotation of the airfoil coordinate due to angle of attack

For calculating t, the height of airfoil, the following method of considering geometric location of coordinates is introduced. Figure 5 is rotation of the airfoil coordinate due to angle of attack.

In this case, (x, y) represents the coordinate of a particular point of the airfoil and (x', y') represents the corresponding coordinate after the rotation. The rotation due to angle of attack is expressed by the angle.

By using the Pythagorean Theorem, the following equation can be deduced, and s is introduced for the purpose of simplification for further derivation:

$$x^2 + y^2 = x'^2 + y'^2 = s \tag{5}$$

By using trigonometric identity, the following equations can also be deduced:

$$\theta_1 = \arctan\left(\frac{y}{x}\right) \tag{6}$$

$$\theta_2 = \arctan\left(\frac{y'}{x'}\right) \tag{7}$$

The angle of attack θ can be expressed as:

$$\theta = \theta_1 - \theta_2 = \arctan\left(\frac{y}{x}\right) - \arctan\left(\frac{y'}{x'}\right) \tag{8}$$

By rearranging this equation, the following equation can be derived:

$$y' = x' * \tan\left(\theta - \arctan\left(\frac{y}{x}\right)\right) \tag{9}$$

By substituting this equation into Eq. (3), the following equations can be derived:

$$x'^2 + x' * \left[\left(\theta - \arctan\left(\frac{y}{x}\right)\right)\right]^2 = s \tag{10}$$

$$x' = \sqrt{\frac{s}{1 + \left(\theta - \arctan\left(\frac{y}{x}\right)\right)}} \tag{11}$$

$$y' = \sqrt{\frac{s}{1 + \left(\theta - \arctan\left(\frac{y}{x}\right)\right)}} * \tan\left(\theta - \arctan\left(\frac{y}{x}\right)\right) \tag{12}$$

Thus, knowing the angle of attack (for rotation) and also the initial coordinates of a particular point, the point's corresponding final coordinates can be calculated. As mentioned previously, the height of the airfoil, which is measured from the highest point to the lowest point of the airfoil vertically; knowing the y coordinates of all points of airfoil after rotation, the final formula for calculating the height is expressed as the following:

$$t = \max(Y) - \min(Y) \tag{13}$$

where Y is the set of all vertical coordinates of the airfoil point after rotation due to angle of attack.

By substituting the values of various parameters into Eqs. 1 and 2, the drag coefficient and lift coefficient under different input values of aspect ratio and angle of attack can be obtained. The results of the numerical results will be analyzed later in the discussion section.

3 Results and Discussion

3.1 Result

By utilizing the methodology presented in the previous section, i.e. the flow simulation from solidworks and also the numerical calculation from python programming, the following results regarding the performance of NACA 24112 could be obtained.

It could be observed from Fig. 6 that universally, for all sets of angles of attack, the increase in aspect ratio would contribute to the better performance of airfoil NACA 24112 by increasing the lift to drag ratio (LDR). By increasing the angle of attack, the LDR would increase initially; however, after the angle of attack of 10°, the increase in AOA would correspond to a lower LDR. By considering the all possible scenarios presented by the different combinations of angle of attack and aspect ratio, the best alternative of geometry and rotation would be the aspect ratio of 2 at the angle of attack of 5°, which has the optimum LDR value of approximately 5.955.

From Fig. 7, it can be observed that both the increase in aspect ratio and angle of attack would contribute to the increase in drag coefficient. In this case, the maximum drag coefficient of the combination of aspect ratio of 2 and angle of attack of 20° is approximately 2.3207; the drag coefficient of optimum LDR value, i.e. aspect ratio of

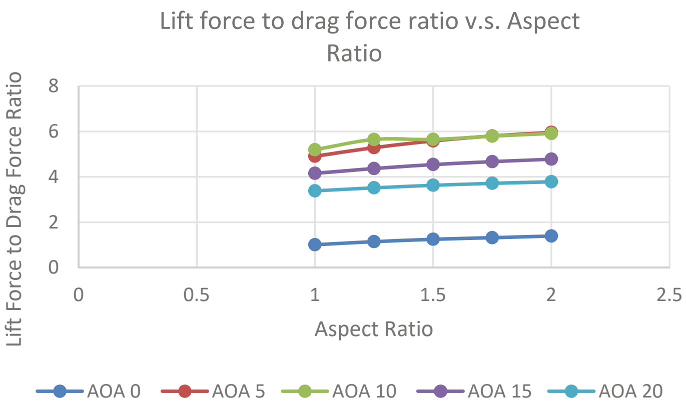
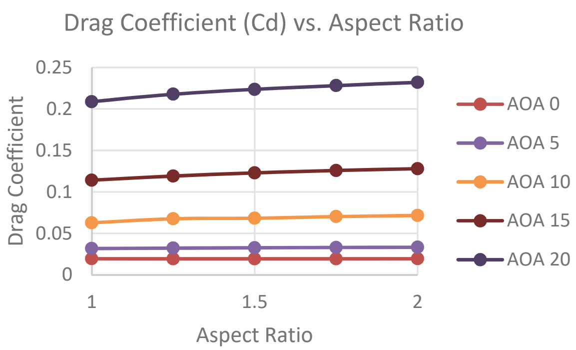


Fig. 6 Lift force to drag force ratio versus aspect ratio

2 at the angle of attack of 5 is approximately 0.03327. The drag coefficient for typical streamlined body of 4-element (which is similar to the airfoil utilized on airplanes in real life situations) is approximately 0.05; this would signify at the optimum LDR case, the value of drag coefficient would be acceptable since it is lower than that of a typical streamlined body [8].

From Fig. 8, a similar trend of lift coefficient variation could be observed compared to that of the drag coefficient, which is that both aspect ratio and angle of attack have a positive correlation in regards to lift coefficient. In this case, the maximum lift coefficient of the combination of aspect ratio of 2 and angle of attack of 20 is approximately 2.2194; the lift coefficient of optimum LDR value is approximately 1.24868. This value of lift coefficient could also be acceptable as it is similar to the typical maximum values of lift coefficient for other NACA series airfoil, which is approximately 1.4 [9].

Fig. 7 Drag coefficient versus aspect ratio (for different AOAs)



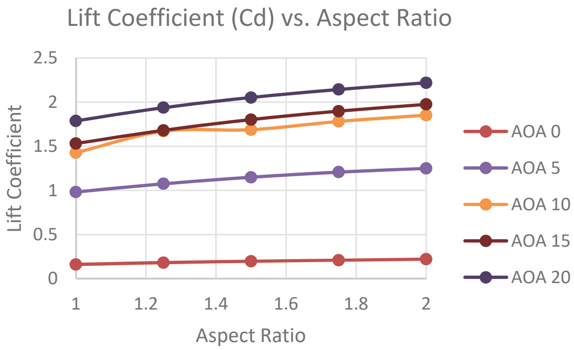


Fig. 8 Lift coefficient versus aspect ratio (for different AOAs)

3.2 Evaluation

Even though a successful simulation and exploration of the optimum performance of NACA 24112 airfoil has been conducted in this paper, there is still room for improvement for the purpose of obtaining more accurate results and more generalized conclusions. The first strategy would probably be to increase the step size, i.e., to examine more values of angles of attack and aspect ratios since there are only 5 different values of angles of attack and 6 for that of aspect ratio.

The second strategy would be exploring the airfoil with more components or more variation regarding geometry in addition to changing the aspect ratio.

As shown by the Fig. 9, the airfoil lift coefficient could be enhanced by having additional components in different configurations of geometry, e.g. double slotted flap, plain flap etc. [10]. Those values are above that for the airfoil only of 1.4 (shown in the Fig. 4) or 1.249 for NACA 24112 airfoil only. For future exploration of the optimized performance for the NACA 24112, various additional components could be utilized e.g. flap. Nonetheless, the results obtained from this paper are still legitimate and could be considered as a preliminary test for airfoil optimization that would lay the necessary foundation for future exploration.

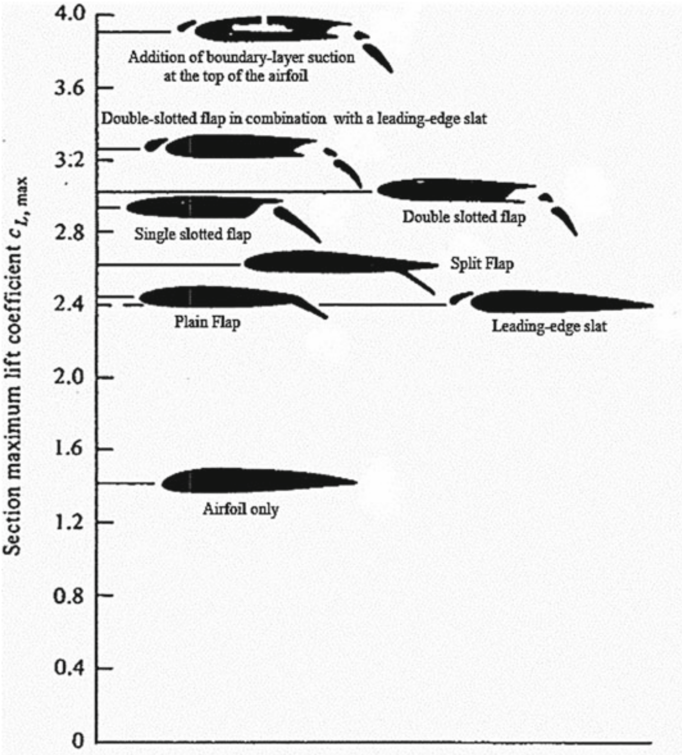


Fig. 9 Typical values of airfoil maximum lift coefficient for various types of high-lift devices

4 Conclusion

Because of the research on the performance of NACA 24112 airfoil, it can be concluded for the optimization of its performance, the aspect ratio and angle of attack shall be selected as 2 and 5°, respectively, with a LDR value of 5.955. In this case, the drag coefficient and lift coefficient are approximately 0.0333 and 1.249 approximately which are both acceptable values in comparison to the typical value of drag coefficient and lift coefficient for streamlined bodies. During the process of research, the solidworks flow simulation and python numerical calculation (for calculating the height of airfoil in particular) have been utilized, which contributed to the final data collection and following discussion of the results. There are certain limitations of the exploration of performance of NACA 24112 in this paper and for the purpose of better accuracy of the results, two alternatives could be applied for future work, which are having a smaller step size for aspect ratio and angle of attack and constructing additional components (to obtain a higher value of lift coefficient).

References

1. Jian-Fei LI, Zhao TY, Zan SD (2016) Effect of angle of attack on the high-speed oblique penetration capability of long rod projectile. Sci Technol Eng 56(7):120–128
2. Yavuz K (2010) Performance analysis of the airfoil-slat arrangements for hydro and wind turbine applications. Energy 87(5):1591–1601
3. Zhaoyang S, Feng H, Jiancheng YU (2022) Influence of autonomous sailboat dual-wing sail interaction on lift coefficients. J Ocean Univ China: English Edition 21(3):13
4. Mobedi P, Lavasani AM, Abolfathi S (2022) The aspect ratio effect on the performance of a cam-shaped cylinder in crossflow of air. Exp Heat Transf 35(4):500–515
5. Giordano R, Ianiro A, Astarita T (2012) Flow field and heat transfer on the base surface of a finite circular cylinder in crossflow. Appl Therm Eng 49(1):79–88
6. Takahashi Y, Watanabe Z (2018) The positioning effect of air-passage-ports in a cylinder on the performance of an air rock-drill 36(12):3240–3244
7. Kagawa M (2013) A Study on the meter-out velocity control of a pneumatic cylinder Consideration of air temperature change effects. Hydraul Pneum 545:225
8. Kaufman DV, Ryabinin AN (2020) Effect of coaxially mounted disks on oscillations of a cylinder of large aspect ratio in air flow. In: IOP conference series: materials science and engineering, vol 927, no 1, p 012002
9. Hamidreza B, Arash B (2014) Experimental study of convective heat transfer from in-line cam shaped tube bank in crossflow. Appl Therm Eng Des Process Equip Econ 797:67
10. Mangrulkara CK, Dhoblea AS, Deshmukha AR (2017) Numerical investigation of heat transfer and friction factor characteristics from in-line cam shaped tube bank in crossflow. Appl Therm Eng 110:521–538