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Feasibility Study of Concave Wing Design for Subsonic Aircraft (NACA 2412)

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Abstract: In this current world of technology, airfoil has been produced for concave wing in many different shapes in terms of root size, tip, existence of winglet and different thickness. Concave wing is the tendency of a wing to bend during flying at a certain height of deflection. It increased higher velocity of the aircraft, mainly due to the increase of lift force produced above the wing. However by SolidWorks, airfoil design for concave wing with NACA 2412 has been choosen. In this study, 0.2m deflection shows the highest lift coefficient and lift drag ratio compared to other height of deflection. The maximum value of C_L obtained is 1.517, while for C_L/C_D is 37.708. This indicates that the airfoil can produce high lift even at low angle of attack, which is beneficial when aircraft wants to take-off, climbing and landing.

Keywords: Lift Coefficient, Lift to Drag Ratio, height of deflection

1. Introduction

Aerodynamics is the study of air forces which affected by a solid object, such as airplane wing. It defines how an airplane can fly. The air which passes the wing creates a force called lift and gravity is the force that oppose lift. Same concept goes to thrust which provides forward force and drag which opposes the thrust. Aerodynamics are important since it controls how much lift that the object will achieve, while reducing the drag in the form of obstacles. The production of lift contributes to the creation. Concave wing is one of the process by bent the wing with curtein height of deflection. The process or deflection will create small vortex which increased lift coefficient.

The production of lift contributes to the creation of induced drag. Induced drag is the drag that is produced as a side product of lift [1]. In real life situation, induced drag causes the net lift to be reduced significantly, causing wastage and inefficiency. Some ways to reduce the induce drag includes having a bigger wing aspect ratio and using different type of wing, such as rectangular and tapered wing. However, having a big aspect ratio will not benefit the design on ground, since it will take up a lot of space just for an aircraft. On top of that, a whole new legislation will be required to ensure the safety paramount of wellbeing is maintained. In this study, the wing curvature is studied to determine any small or significant difference in the lift generation and drag reduction.

Wing curving is not much difference than wing morphing [2]. Instead of changing the wing's shape and structure, it bends its wing towards the tip of airfoil, creating a deflection like bending. This study is focused on wing curving. Therefore, the aerodynamics characteristics of the wing is studied. Table 1 shows the differences between wing morphing and wing curving.

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Table 1 - Differences of wing morphing and curving

Wing Morphing	Wing Curing
Changes its shape and structure	Does not change its shape and structure
Involves multiple complex systems to operate	Involves only deflection of wing to create curving
Increase in complexities increases cost	Less complexity, reduce in cost
Beneficial in military aviation	Beneficial in commercial aviation

In conducting a review, several phases have been executed and every phase explained thoroughly in the following subsections.

2. Methodology

Lift Coefficient, C_L, is a number used in relation to determine the aerodynamics characteristics of a wing. It uses complex dependencies such as shape, inclination and some flow conditions on lift. C_L is closely related to the angle of attack of the wing [3]. The value C_{Lmax}max is very important because it determines the aircraft's minimum speed at which it can fly. After many years of research and experiments, researchers back then have managed to come up with a formula that benefits the manufacturers and nowadays researches in creating more efficient wing [4].

$$C_L = \frac{2L}{\rho V^2 S} \tag{1}$$

Drag Coefficient, C_D, due to skin friction, interference of airflow and many other minor factors. In the same way C_L affected by angle of attack, C_D affects as well. It measures its effectiveness of the wing to reduce the air resistance [5]. Based on equation 2, it shows that the lower $C_D$value gives a better results of streamline shape, which helps to produce lift better.

$$C_D = \frac{2D}{\rho V^2 S} \tag{2}$$

Lift to Drag Ratio, C_L/ C_D, is deduced as how much lift can be produced compared to how much drag is produced. The greater the value of C_L/ C_D, the greater the lift produced.

2.1 Wing Morphing

Wing morphing is the ability for the wing to transform its shape or structure. In order to achieve maximum efficiency of flight, the wing should morph according to the corresponding target and requirements during flight [6]. The complexity and cost of manufacturing can also be reduced. With this advancement, there could less requirement for production of aircraft to fit different criteria, such as flight duration and capacity of the aircraft to transport passengers. In other word, an aircraft can be built with many other requirements and purposes, without having to increase the cost of production.

In current wing design, there are wing morphing concept that has been used. For example, flaps and slats. Slats are located at the leading edge of the wing. It not only promotes noise reduction due to turbulent boundary layer occurring before that, but also creating a laminar flow, which directly improve the relative airflow of the aircraft, increasing its efficiency [7].

Another good example of wing morphing is F- 14 Tomcat. Its recognisable change in wing shape has made it one of the best fighter planes built in military aviation. Its wing morphing has managed to increase its flight speed and achieving Mach 1 in merely seconds after deploying its morphing [2].

3. Results

3.1 Wing Configuration

The airfoil that is used is NACA 2412. Based on the number value of the airfoil, it represents certain meaning to it. The first digit, 2, is the maximum camber. It can be divided by 100. Therefore, it means that the maximum camber is located at 0.02 or 2% of the chord line.

Next digit, 4 represents the position of the maximum camber. It can be divided by 10. In this study, the number means that the maximum camber is located at 0.4 or 40% of the chord line. The final two digits, 12, represents the maximum thickness. It can be divided by 100. Thus, the maximum thickness is located at 0.12 or 12% of the chord line.

A set up is needed to ensure that all the configuration are set to a standard configuration. The set up configuration is used for all deflection airfoil. Table 2 shows the wing configuration that is used in this study.

Table 2 - Wing configuration of NACA 2412

Characteristics	Value
Wing area (m^2)	2.000
Wingspan (m)	4.000
m.a.c	0.300
Taper ratio	1.000
Aspect ratio	8.000
Swept angle (°)	0.000
Tip chord (m)	1.000
Root chord (m)	1.000

3.2 CFD Simulation using Solidworks

In this study, SolidWorks is used because it possess both design and flow simulation capabilities, which suits the purpose of this study. SolidWorks is a software used mainly by engineers to design an object and carry out further study the analysis of the object in term of structural analysis and flow simulation [8]. After the airfoil is designed, flow simulation is then carried out to run the aerodynamics performance of the airfoil. The configuration is set at ISA standard and the velocity is set at 100 m/s for all airfoils. There are 5 airfoils in total; normal configuration airfoil, 0.1, 0.2, 0.3 and 0.4 deflection airfoil. Fig. 1 (a) shows airfoil deflection another Fig. 1 (b) shows airfoil in a fluid domain. The airfoil is built and simulated in SolidWorks as it has the capability to do flow simulation and its calculation as well.

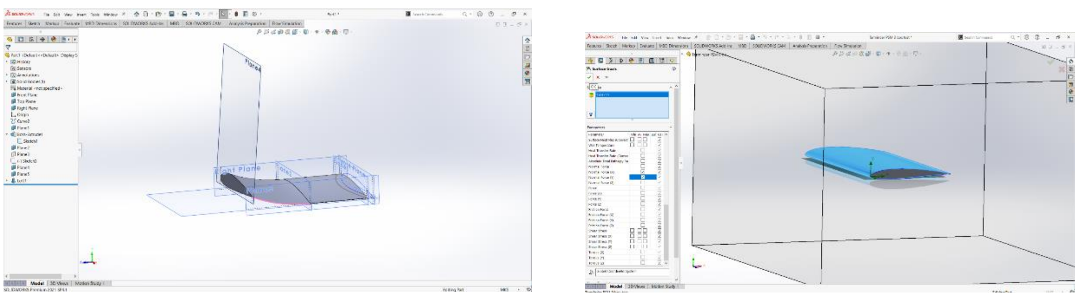

Fig. 1 - (a)- airfoil deflection; (b) airfoil in a fluid domain

4. Discussion

The analysis displayed in this chapter is executed by SolidWorks and further discussion is made according to the graph obtained. The performance of each airfoil is described in terms of C_L vs α and , C_L/ C_D vs α graphs. Fig. 2, Fig. 3, Fig. 4, Fig. 5 and Fig. 6 shows the difference on velocity contour graph at 0° degree and 8° degree angle of attack with different deflection. All figures below shows different deflection which are at normal configuration 0.2m, 0.3m and 0.4m deflection. Fig. 2 with normal configuration or zero deflection and 8° degree angle of attack have high velocity.

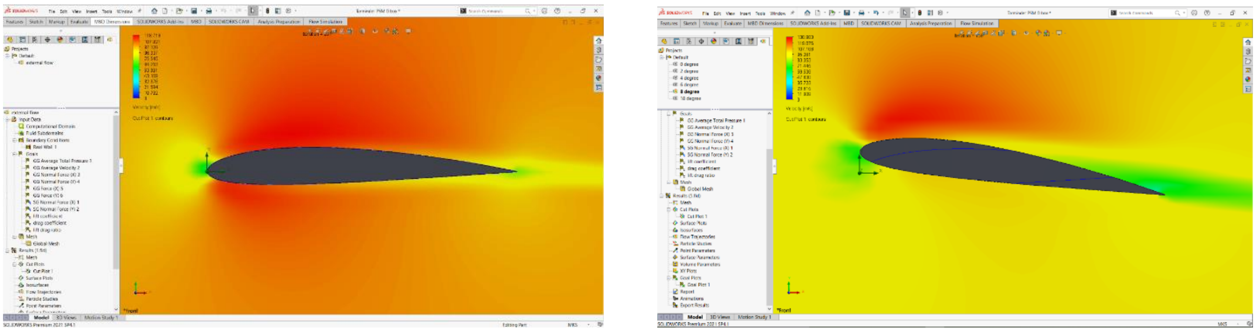

Fig. 2 - Velocity contour graph at 0° and 8° angle of attack at normal configuration

Fig. 3. Have increased deflection about 0.1m, but for 8° degree angle of attack shows decreased in velocity profile compared to airfoil with 0° degree angle of attack.

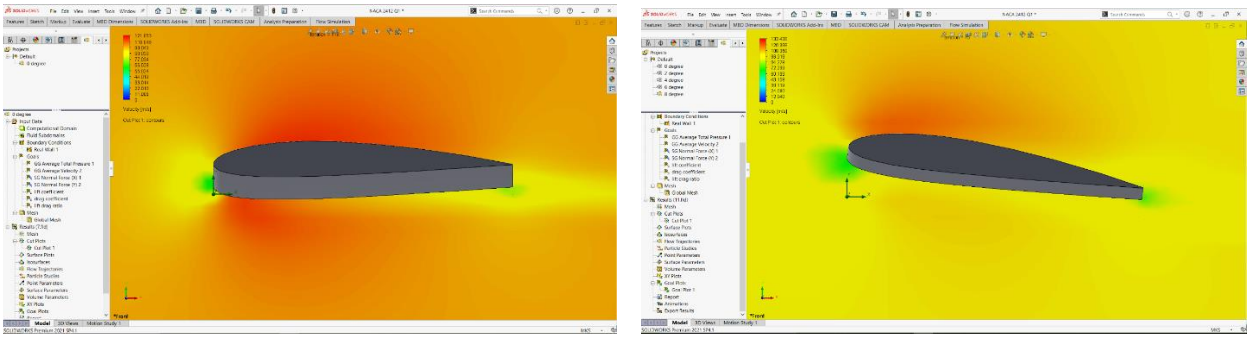

Fig. 3 - Velocity contour graph at 0° and 8° angle of attack at 0.1m deflection

0.2 m deflection in Fig. 4 shows best design for highest lift coefficient (C_L) and lift drag ratio compared to other height of deflection. It was approved through the results at Fig. 7 and Fig. 8.

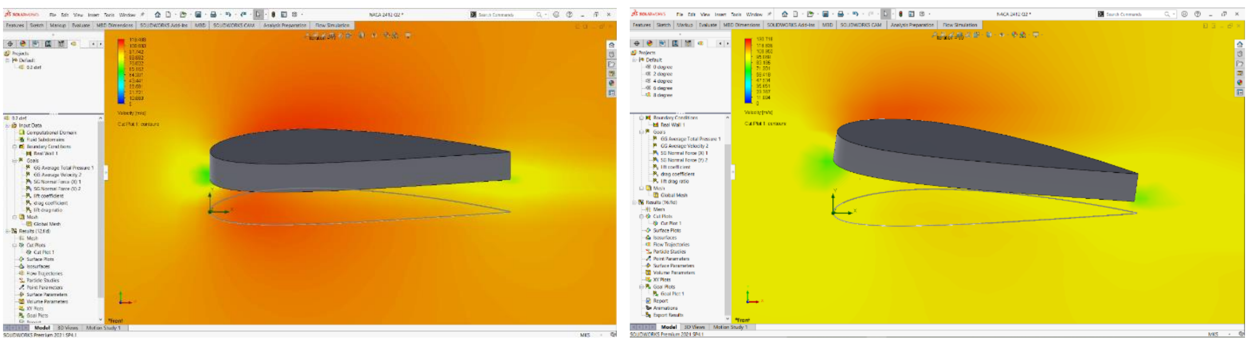

Fig. 4 - Velocity contour graph at 0° and 8° angle of attack at 0.2m deflection

Fig. 5 shows that reduced in velocity especially at 8° degree angle of attack even though the deflection become bigger which is 0.3m.

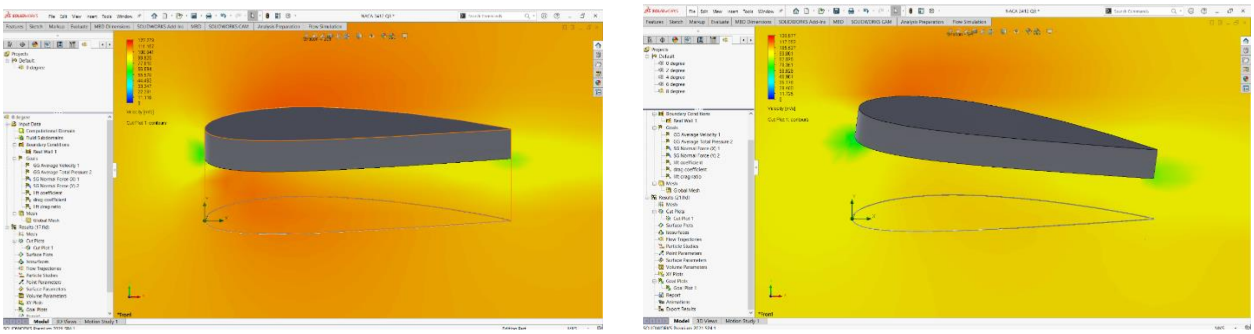

Fig. 5 - Velocity contour graph at 0° and 8° angle of attack at 0.3 m deflection

The more bigger in deflection, the less in velocity profile. It shows in Fig. 6.

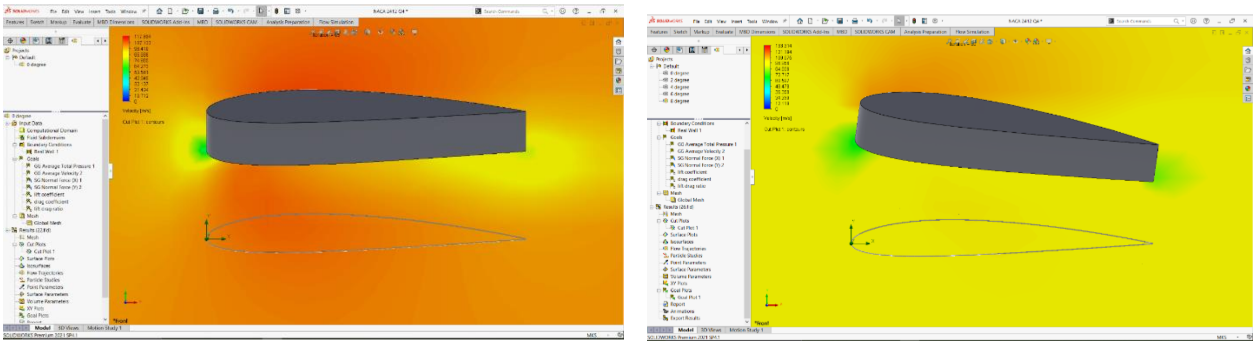

Fig. 6 - Velocity contour graph at 0° and 8° angle of attack at 0.4 m deflection

Deflection at normal configuration which shows in **Error! Reference source not found.**degree angle of attack. Fig. 7 below shows the results on lift coefficient (C_L) with different angle of attack.

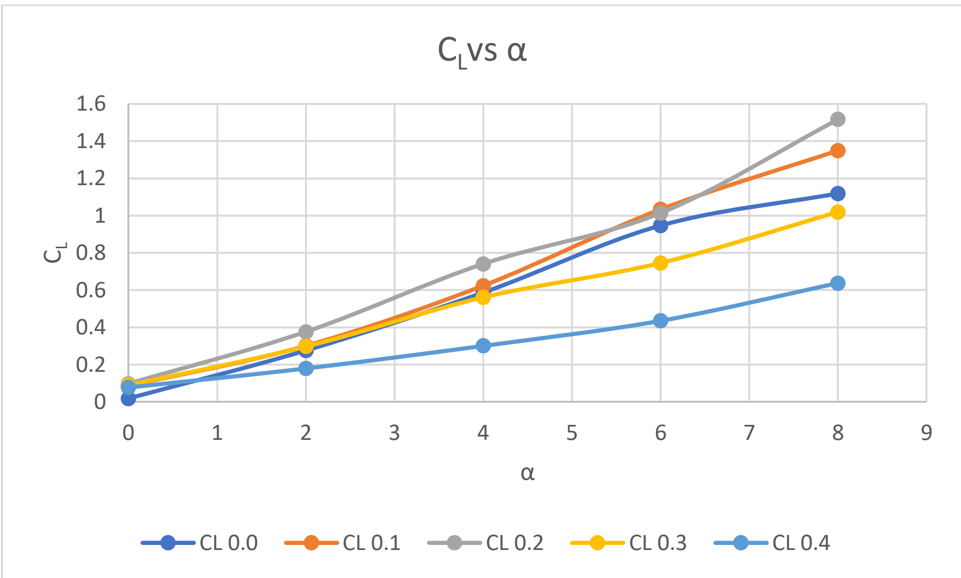

Fig. 7- C_L vs α from 0° to 8° angle of attack

When looked at Fig. 7, all lines show an almost linear increase. However, the gradient when seen from the trendline is different. Results from 0m deflection airfoil to 0.2 m deflection line give an increase of gradient from the lines. This indicates that the C_L occured higher at the given angle of attack. From this results, it is deduced that when C_L increased based on the deflection of the airfoil. 0.2 m deflection shows the highest reading of C_L at 8° angle of attack. This indicates that based on the data collected, that airfoil can operate better by producing a higher lift compared to the other 2 airfoils with have 0.3m and 0.4m deflection.

In 0.3 m deflection airfoil, the result shows a consistency with 0m, 0.1 m and 0.2 m deflection airfoil up to 4° angle of attack. However, the line did not increase consistently after 4° angle of attack. In the end, the C_L cannot produced as good in 0.3m deflection airfoil compared to the previous airfoils. It can be assumed that the airfoil begins to produce less lift coefficient as the angle of attack reached 0.3m deflection or more. This airfoil can reach stall angle at a lower C_L, decreasing its efficiency when in subsonic flight.

In 0.4 m deflection, the airfoil produces a much smaller C_L as the angle of attack progresses. It can be shown in Fig. 7, where the velocity that is produced in the upper surface of the airfoil is not much, which strongly indicates that the airfoil is not producing much lift coefficient. Therefore, it can possibly reach stall angle at a much smaller C_L compared to 0.3 m deflection airfoil.

Fig. 8, shows 0.2 m deflection airfoil has the highest value of C_L/C_D, at 37.71 at 8° angle of attack. This contributes to a higher lift to drag ratio when flying at a higher angle of attack.

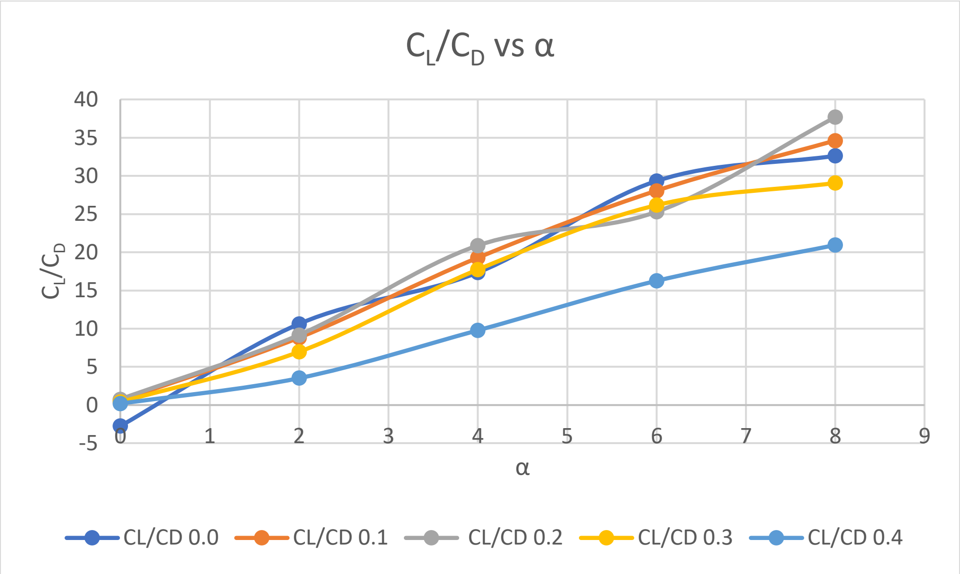

Fig. 8- C_L/C_D vs α at 0° to 8° angle of attack

There is a huge difference in value of C_L/C_D for 0.4 m deflection airfoil compared to the other airfoils. This is mainly due to the value of C_L as the angle of attack increases in the airfoil. The increasing value of C_D also affects the results. NACA 2412 airfoil produced low lift to drag ratio, therefore it is not suitable to be used for subsonic aircraft, since subsonic aircraft produces high lift at a lower velocity.

5. Conclusion

Based on the results presented in the research, it is deduced that airfoil with 0.2 m deflection produced the highest C_L value at increasing angle of attack. It also contributed to the higher C_L/C_D value as the angle of attack increases. Given that the validation results show a margin error of less than 5%, this research can be further carried on studying the data obtained at different altitude, Reynolds Number and velocity. A further study should be carried out so that it can one day be applied in the real-world industry and benefit the public and industry together.

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