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Research paper

Study of Subsonic Airfoil Based on the Assessment of Lift-To-Drag (L/D) Force Ratio

Nur Hasalli Hj Ibrahim[1]*, Mohamad Dzulhelmy bin Amari[2], Zainon Sharmila Shamsuddin[3]

[1]*School of Engineering*
KDU University College,40150
Shah Alam, Selangor, Malaysia
Faculty of Mechanical Engineering,
[2]*University Technology MARA (UiTM) ,40150,*
Shah Alam, Selangor, Malaysia
**Corresponding author E-mail: hasalli.i@kdu.edu.my*

Abstract

This paper focuses on the symmetrical model of NACA 0012 and performance of lift and drag forces to maintain the lift-to-drag (L/D) force ratio while cruising at air. The design modifications have been investigated to enhance the lift-to-drag force ratios for the subsonic airfoil. Initially, the study was conducted on the 2-D airfoil model of NACA 0012 and the results were compared experimentally and simulation using ANSYS 17.2 for all the conceptual designs. The analysis consideration for the airfoils design was indicated at 36 m/s constant velocity and zero angles of attack. The best possible conceptual design was developed which can perform at high lift forces, low drag forces and a high ratio of the lift-to-drag forces. It was found that the opportunity in the optimization of the subsonic airfoil based on the various effect of aerodynamic characteristics will be able to enhance the performance of subsonic airfoil.

Keywords: *Drag Coefficient, Lift Coefficient, Lift-to-Drag Ratio, NACA 0012.*

1. Introduction

In the theory of flight, an airfoil is a body shaped to produce an aerodynamic reaction and one of the main structure when designing the airplane, rocket, helicopter and others [1]. Most of the studies about airfoils often done to have high lift and low drag forces as much as possible in a way to optimize the performance of airfoils. Generally, when the air flowing around the airfoil, an interaction between the airfoil and the air occurs that produces two main forces which are lift force and drag force from the center of pressure as shown in Figure 1 [2,3].

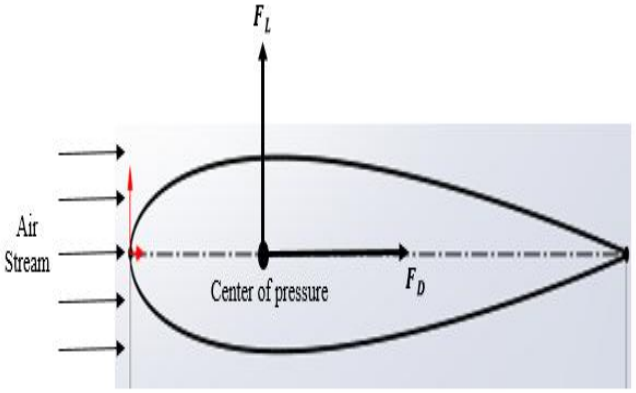


Fig. 1: Airfoil Nomenclature

The lift force is the perpendicular force from the direction of motion and the drag force is the horizontal resistance force of the plane. Basically this two forces associates with the dimensionless coefficient that known as lift coefficient (C_L) and drag coefficient (C_D). This two coefficients give a different effect towards the airfoil where the lift coefficient is acting around lifting body that can be defined as a foil or complete foil-bearing body such as aircraft which function as an angle of the body to the flow, its Reynold number and the Mach number. The general equation of the lift coefficient as shown in equation 1 [2,3].

$$C_L = F_L / 0.5\rho V^2 A \quad (1)$$

The lift coefficient can be found from the fractional of lift force, F_L, to the density of the air, ρ, velocity of the air stream, V, and the frontal area, A, that measure from area projected on a plane normal to the direction of the flow. While, the drag is the resistance of an object on a fluid environment, such as air or water. The lower drag coefficient indicates the object will have less aerodynamic. The general equation of the drag coefficient is given as in equation 2 [2,3].

$$C_D = F_D / 0.5\rho V^2 A \quad (2)$$

The consequence of airfoil shape and size are important in optimization the aerodynamic characteristics which useful in the efficiency and performance of the aircraft. There are a lot of research performed on designing various airfoil shapes and geometries to explore the potential of minimum drag force and the maximum lift force [4]. Hossain et al. [5] conducted an experimental to measure the lift and drag coefficients for the wing with and without bird feather like winglets for different Reynolds Number. The experimental result shows that 25~30% reduction in drag coefficient and 10~20% increase in lift coefficient by using bird feather like winglet at 8-degree angle of attack. Dwivedi et al. [6] use a simple approach for experiment on aerodynamic static stability analysis of different types of airfoil. They tested the small scale of airfoil for different shapes like rectangular, rectangular with curved tip, tapered and tapered with curved tip in low speed subsonic wind tunnel at different speeds and different angles of attack. The outcome from their research was found that the tapered wing with curved tip was the most stable at different parameters. Talluri et al. [1] designed various types of airfoil to increase the lift coefficient and lower the drag coefficient as much as possible and found that the best configurations for the lift and drag coefficients is when the airfoil was flap at 15 degree and slot at trailing edge and also when used a gurney flap with flat wedge support. The use of flaps in airfoil able to enhance the lift-drag and stabilize the aircraft.

Improper design of airfoil will lead to high wingtip vortices which formed when the pressure on upper surface were highly different with the lower surface of the airplane's wing. High pressure on the lower surface of the airfoil creates a flow that flows and curls upwards around the airfoil. This phenomenon will produce vortex and energy losses in the airplane surrounding. Thus, the optimization of airfoil capable to boost the performance of airplanes by reducing the drag force, high lift force and high lift-to-drag efficiency [7]. In this research, the design of the airfoil should have high lift and low drag characteristics to increase the lift-to-drag force ratio and produce better performance.

2. Methodology

2.1. Conceptual Design Modelling

There are three conceptual designs created based on the specification of NACA 0012 model to measure the performance of subsonic airfoil that can enhance the lift-to-drag (L/D) force ratio. NACA 0012 is a symmetrical geometric airfoil with the equivalent span size in upper and lower surface. The conceptual design 1 (CD 1), conceptual design 2 (CD 2) and conceptual design 3 (CD 3) was designed using Solidworks 2017 with the different size and dimensions such as different thickness, length of the upper surface to lower surface ratio and shape. The schematic diagram of the airfoil model is shown in Figure 2.

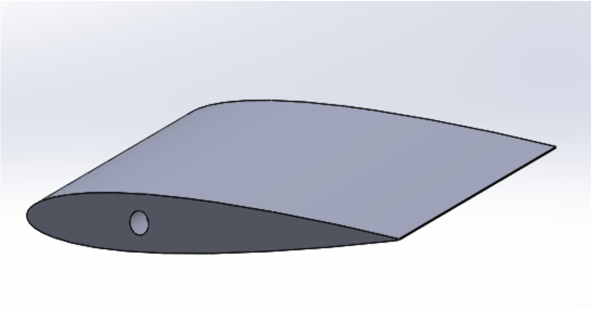


Fig. 2: Isometric view of NACA 0012 airfoil

The actual geometries of NACA 0012 was scaled down to meet the equipment requirement. Before the design imported to simulation software, the three conceptual designs was sketched on an Excel format file to jot down the specific locations of each dot of the outline in the x,y,z plane. Then, the file is inserted into the Solidworks software for further extrusion and import to ANSYS 17.2 software for editing process and generate the results. The aerodynamic performances such as the lift and drag, pressure distribution, velocity, pressure contours, velocity contours, streamlines, pathlines and the lift-to-drag coefficient ratio was recorded and analysed.

2.2. Computational Fluid Dynamic (CFD) Simulation

In order to achieve the objective, the computational fluid dynamics (CFD) approach was used. The geometry of airfoil was imported to ANSYS Fluent and edited the model using Design Modeler to meet the software requirement. The insertion of enclosure was created and functioning as a fluid volume significant with the inlet velocity, outlet and a walls of the wind turbine. This is important to simulate under same condition as in the wind tunnel experimental method. The material parameter has been setup where the medium of the fluid was set under air condition and define the standard density and viscosity of the air. The airfoil material was set as ABS plus material and airflow characteristics is set as a laminar flow at constant velocity, 36 m/s and zero-degree angle of attack.

In designing the airfoils, there are three methods that can be used which is geometrical construction, conformal transformation and physical transformation. The method of geometrical construction was applied in designing the model of airfoils which adapted from Karmann-Treffz profile airfoil. The main consideration factor in designing the airfoil is in terms of the thickness, mean chamber thickness, zero lift angle and the lift and drag coefficients value [9].

2.3. Fabrication of 3D Modelling

The 3D modelling of all the airfoils was printed out using MOJO 3D printer. The Solidworks file was imported to the 3D printer software with the 1:1 scale ratio in between the design and the actual product. To insert the 3D model into the wind tunnel, a slot hole was created to fix with the mounting part of the wind tunnel. The 3D models was cleaning from the excess impurities and smoothing the surface of 3D models. Figure 3 shows the final product of airfoil after fabrication process.

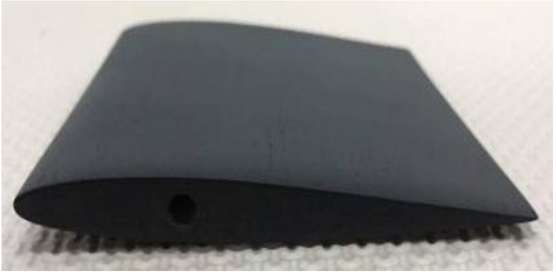


Fig. 3: Prototype of NACA 0012

2.4. Experimental Procedure

Techquipment subsonic wind tunnel was used in analysing the aerodynamic characteristics for all the airfoils. The prototype airfoil was placed inside the working section that located between the effuser or inlet cone and the diffuser. The velocity was set at the constant value of 36 m/s and the angles of the model was set to zero degree. Figure 4 shows the position of the airfoil model inside the working section in wind tunnel. Then, the lift force and drag force was recorded for the comparative analysis with simulation data.

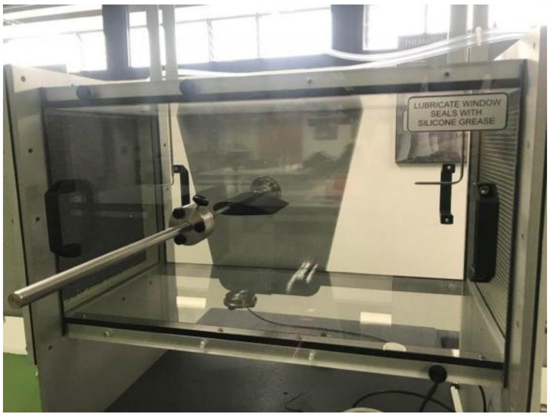


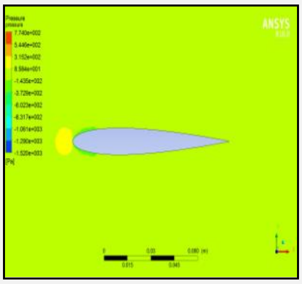
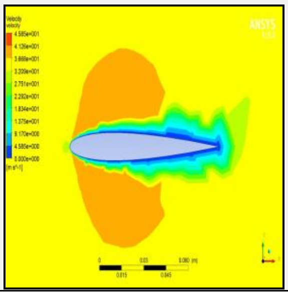
Fig. 4: Experimental analysis using wind tunnel

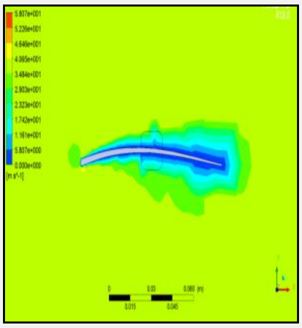
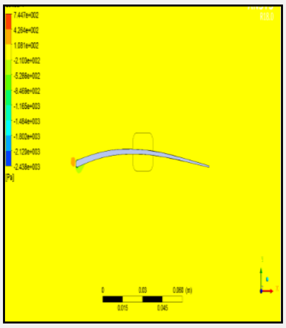
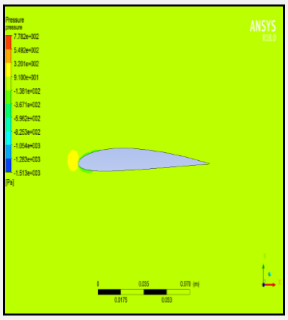
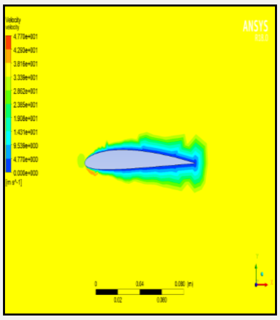
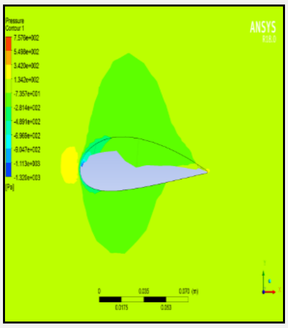
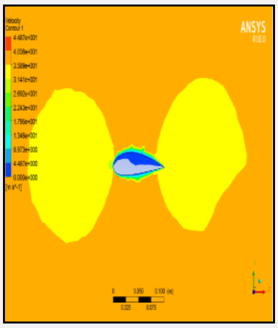
3. Result and Discussion

3.1. Simulation result

Table 1 shows the illustration of simulation result for all types of airfoil. From the data in Table 1, it is apparent that the contours of static pressure at zero angle of attack was different for every models. For NACA 0012 airfoil and conceptual design 2, the static pressure was greater at the leading edge while for the conceptual design 1, the pressure is focusing on the trailing edge and the pressure was greater at the lower surface of the airfoil compare to the incoming air stream. This result shows that the pressure able to force the airfoil upward in the normal direction of the air stream. However, the pressure was greater at upper surface for the conceptual design 3. The distribution of the parallel pressure can contribute to the slow velocity in the incoming air stream of the airfoil and this also can affect the viscous stresses [8]. The contours of velocity components at zero degree of attack also shows in Table 1. There are various result shown for every model of airfoils. The velocity are high at the leading edge and slowing down when it jumped to the trailing edge point.

Table 1: Simulation result for all types of airfoil at zero angle of attack

Pressure Contours	Velocity Contours
NACA 0012 	NACA 0012 

Conceptual Design 1 	Conceptual Design 1 
Conceptual Design 2 	Conceptual Design 2 
Conceptual Design 3 	Conceptual Design 3 

3.2. Experimental result

Table 2 and Table 3 shows the lift force and drag force data gained from the wind tunnel experiment. The lift coefficient and drag coefficient value was determined from the equation 1 and equation 2 after recording the lift and drag forces value using wind tunnel. From the lift force data, the highest lift coefficient value was recorded by conceptual design 1 while the model NACA 0012 lift coefficient data is the lowest value. As can be seen from Table 3, the drag coefficient value is slightly lower than lift coefficient with the best value recorded by the conceptual design 2. Besides that, the drag coefficient value of conceptual design 2 is close with the model NACA 0012.

Table 2: Lift force data

Types of Aerofoil	**Air velocity (m/s)**	**Frontal area (m^2) X 10^{-3}**	**Lift coefficient**	**Total lift (N)**
NACA 0012	36	1.201	0.02	0.019
CD1	36	0.773	2.62	1.599
CD2	36	1.020	0.74	0.596
CD3	36	2.394	0.37	0.709

Table 3: Drag force data

Types of Aerofoil	**Air velocity (m/s)**	**Frontal area (m^2) $\times 10^{-3}$**	**Drag of model (N)**	**Drag of dummy stem (N)**	**Total drag (N)**	**Drag coefficient**
NACA 0012	36	1.201	0.61	0.54	0.07	0.06
CD1	36	0.773	0.90	0.53	0.37	0.59
CD2	36	1.020	0.615	0.55	0.065	0.08

CD3	36	2.394	0.81	0.59	0.22	0.12

3.3. Data summary

Table 4, Table 5, Table 6, and Table 7 compares the summary of all the data collected thru experimental, calculation and simulation. It is apparent from this table that very few different value recorded for each model. The comparable results of the lift forces, drag forces and lift-to-drag force ratio also illustrated in the Figure 5, Figure 6 and Figure 7.

Table 4: Model NACA 0012

Parameter	**Exp**	**Calc**	**Simu**
Lift Coefficient	0.020	0.020	0.030
Lift Force (N)	0.019	0.020	0.020
Drag Coefficient	0.060	0.060	0.090
Drag Force (N)	0.070	0.057	0.060
Ratio (L/D)	0.270	0.350	0.330

Table 5: Model conceptual design 1

Parameter	**Exp**	**Calc**	**Simu**
Lift Coefficient	2.620	2.620	2.630
Lift Force (N)	1.599	1.610	1.610
Drag Coefficient	0.590	0.590	0.580
Drag Force (N)	0.370	0.360	0.360
Ratio (L/D)	4.320	4.470	4.470

Table 6: Model conceptual design 2

Parameter	**Exp**	**Calc**	**Simu**
Lift Coefficient	0.740	0.740	0.980
Lift Force (N)	0.596	0.599	0.598
Drag Coefficient	0.080	0.080	0.100
Drag Force (N)	0.065	0.064	0.063
Ratio (L/D)	9.170	9.360	9.490

Table 7: Model conceptual design 3

Parameter	**Exp**	**Calc**	**Simu**
Lift Coefficient	0.370	0.370	0.370
Lift Force (N)	0.709	0.700	0.709
Drag Coefficient	0.120	0.120	0.120
Drag Force (N)	0.220	0.230	0.220
Ratio (L/D)	3.220	3.040	3.220

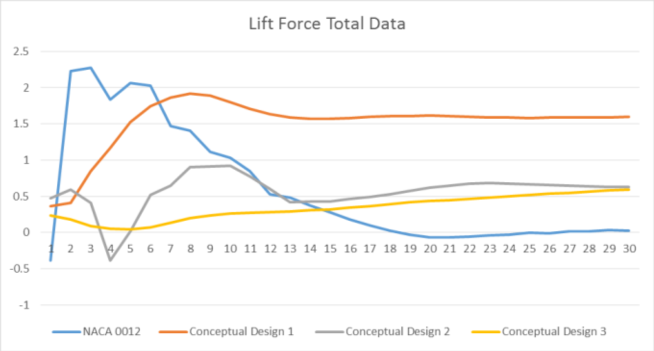


Fig. 5: Lift forces for different design under 30 iterations

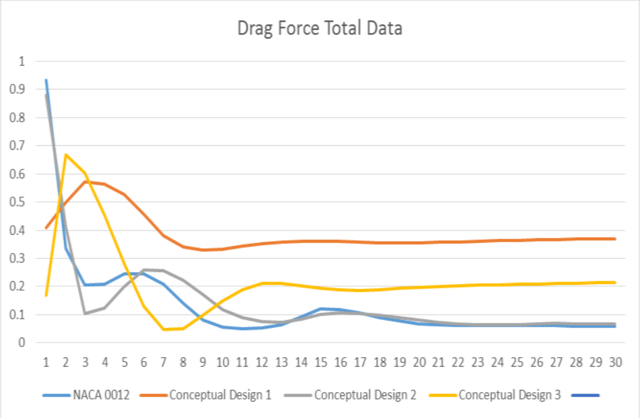


Fig. 6: Drag forces for different design under 30 iterations

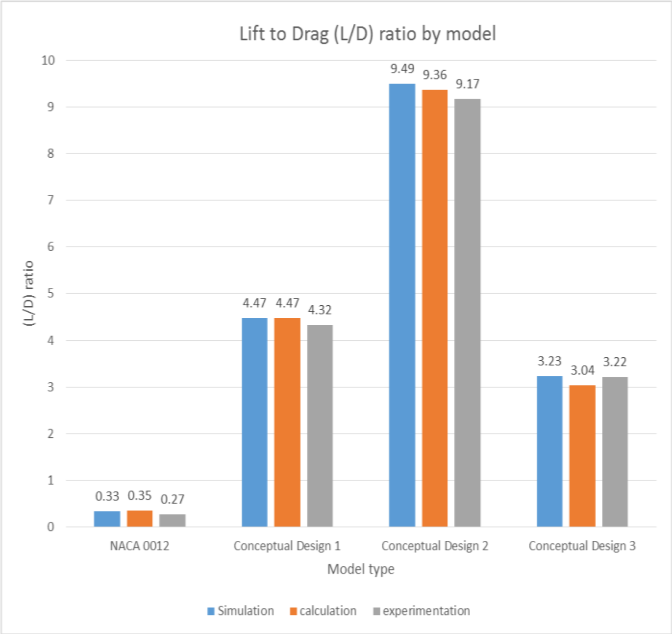


Fig. 7: Lift-to-Drag (L/D) ratio data

From the result gained from the calculation, simulation and experimental, the best result of lift-to-drag force ratio is the conceptual design 2 with the simulation result of 9.46, calculation result is 9.36 and experimental result is 9.17 in comparison with the benchmark model of NACA 0012 which have a simulation result of 0.33, calculation result of 0.35 and experimental result of 0.27. Even the other conceptual design (CD1 and CD3) also show highest result compare to the model NACA 0012.

Essentially, the amount of flow curvature determines the amount of generation of lift. All the models including the NACA 0012 was designed with a chord length of 100 mm and a wing span of 100 mm respectively. The geometry modification lies within the amount of thickness of the airfoil and the amount of curvature imposed to the conceptual design. Conceptual design 2 has more curvature compared to the NACA 0012 and conceptual design 3 so that the conceptual design 2 has the best lift-to-drag (L/D) force ratio. However, the conceptual design 1 has the most curvature compared to all other models. There is a definite explanation need to be investigate further.

4. Conclusion

This paper was undertaken to design the subsonic airfoil and evaluate the aerodynamic characteristic to enhance the performance of lift-to-drag force ratio. The results of this investigation shows that the conceptual design 2 is the best design that can be optimize from the model NACA 0012. All the design can produce better lift-to-drag force ratio compare to the model NACA 0012. The future work that will be done based on the research is to incorporate the different angle of attack for incoming air flow thru the structure. The work that need to be fulfil is to ensure the new airfoil design should be able to optimize the performance of aerodynamic characteristics. Furthermore, verification of analysis data will be compare with other model such as NACA2412 for chambered model.

Acknowledgement

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