



Hydrodynamic analysis of an underwater glider wing using ANSYS fluent as an investigation tool

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ABSTRACT

The analysis of the hydrodynamic behavior of the modified trailing edge of an underwater glider wing was conducted using ANSYS Fluent 18.1. The procedure was carried out using the computational fluid dynamics (CFD) approach. A standard four digits NACA0016 aerofoil profile was selected while the geometry points were extracted from NACA online aerofoil generator using Solidworks, which enabled the creation of the 3D wing profile. Since the focus of the study is more toward hydrodynamic behavior or the influence of the modified round trailing edge as opposed to the normal sharp trailing edge, coefficient of lift (C_L), coefficient of drag (C_d), coefficient of pressure (C_p) and the drag polar (C_d/C_L) are very crucial parameters and have an influence on the accuracy of the results. The results showed lift and drag coefficient are a function of the angle of attack (AOA) and free stream velocities. The investigation showed the optimal design point of the AOA of 12° at the corresponding speed of 0.26 m/s. The critical AOA matched with the optimal design point of 12° . The results also showed that C_p is higher closer to the fuselage and therefore explains why more structural rigidity must be provided in this region of high stress concentration. The drag and lift curve corresponded to the typical wing characteristics of the published experiment data regardless of the operating conditions.

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1. Introduction

The investigation of an aerofoil has been reported in many studies whereby flapping, blunt, and serrated trailing edges are investigated to gain lift and reducing drag [1–6]. These investigations have been performed experimentally and numerically [7–14]. There are a couple of precautions that need to be taken into consideration when one is performing numerical analysis. These include the factors that influence the accuracy of the numerical results i.e. mesh generation, mesh quality, etc. It should be noted that the developments of shapes used for numerical are always based on standard NACA aerofoils [4,7,11–13]. Numerous works have been reported on aerodynamics and hydrodynamics i.e. underwater glider and flights [3–6,13,14]. Javaid et al. [11] have conducted a study of hydrodynamic analysis on different shapes of underwater glider wings. The tapered and rectangular wings were comparatively studied to find the best performing shape.

Gómez & Pinilla [15] conducted a comparative analysis between the blunt trailing edge and sharp trailing towards the aerodynamic

effect. The modification was parameterized by cutting the trailing edge perpendicular in different sections along the chord length. Their findings showed an increase in the maximum lift coefficient, profile drag, and lift coefficient slope. Xie et al., [16] undertook a similar study to determine the effect of the incident angle on the gliding distance of the underwater glider. The results showed the smaller the gliding angle the longer the gliding distance. However, due to the relationship between the gliding angle and the wing incident angle, it was not easy to measure the gliding angle directly. Their findings also showed that the passively rotatable wings can achieve a longer range than the conventional fixed wings if the incident angle is set properly.

This paper reports on the findings of a numerical investigation on the performance of the glider with the round trailing edge wing profile. The main focus was on the influence of the operating conditions such as the inlet speed and angle of attack (AOA) on the hydrodynamic parameters such as coefficient of lift (C_L), coefficient of drag (C_d), coefficient of pressure, and the drag polar (C_d/C_L) as a result of the geometric modification of the trailing edge of the selected NACA wing. The 2D model used in this study was based on the NACA0016.

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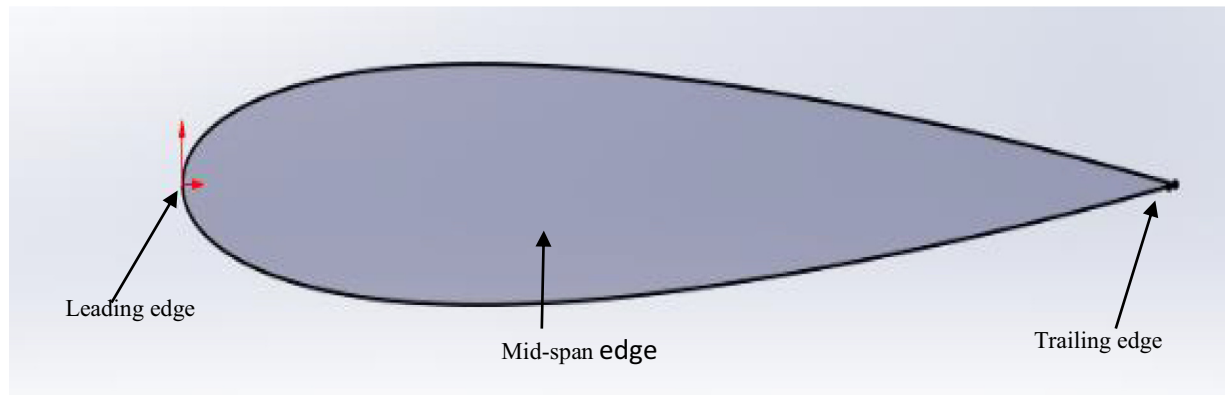


Fig. 1. The 2D wing profile based on NACA0016 aerofoil.

2. Materials and methods

The development of the model was based on the points that are presented in Table 1. These geometry points were imported to Solidworks to generate the profiles shown in Fig. 1. The developed 2D model was based on NACA0016 geometry. The overall summary of the dimensions of the glider wing is presented in Table 2.

The solid model was meshed using the multizone mesh technique (see Fig. 2). The meshing method was set such the unstructured mesh is utilized in areas with high curvature to capture full details of the geometry (see Fig. 3). The fluid domain was created following the guidelines of Javaid et al. [15] and the ITTC guidelines

[18]. The fluid domain upstream boundary was set at 2 times the length of the glider wing; while the downstream boundary was set at 4 times the length of the glider wing. The ceiling-wall of the domain to the wing plane and from the bottom wall domain to the wing plane is 9 times the glider wing diameter [15,17]. The flow turbulent flow around the airfoil was modeled using the following viscous models in ANSYS Fluent: k- ϵ - Standard, k- ϵ - RNG, and k- ϵ - Realizable models. However, the results presented in the next section are from the k- ϵ - RNG model. The selected operating conditions for the analysis are as follows: inlet velocities $v = 0.1$ m/s, $v = 0.26$ m/s, $v = 0.28$ m/s, $v = 0.3$ m/s, $v = 0.4$ m/s and $v = 0.5$ m/s, AOA starting from 2° to 14° with the increment of 2° . A summary of the mesh metrics of the study is given in Table 3 below.

Table 1
Geometry points used in generating wing profile.

Points	X(mm)	Y (mm)	Z(mm)
1	1	0	0
2	1	0	0
3	0.99	0	0
4	0.99	0	0
5	0.98	0	0
6	0.96	0.01	0

Table 2
The glider wing dimensions.

Dimensions	Round trailing edge wing
Wing span	300 mm
Root Chord Length	170 mm
Diameter of the wing	45 mm
Taper Ratio	–
Sweep Angle	90°

3. Results and discussions

The quantitative results of the spatial distribution of pressure, lift and drag coefficients along the upper and lower surface of the glider wing are presented in this section. Fig. 4 shows C_d as a function of the AOA. There a notable nonlinearity between drag coefficient and AOA and this nonlinearity is similar in all velocities. The comparison of different inlet velocities showed the wing achieved more C_d at lower velocities than at the higher inlet velocities [12,14,17].

The relationship between AOA and lift coefficient is presented in Fig. 5. Fig. 5 depicts a linear increase in C_L as the AOA increases until reaches the maximum critical AOA after which it decreases. This decrease suggests that the glider wing reaches a stalling point at approximately $AOA = 12^\circ$ for all inlet velocities.

Fig. 6 shows surface pressure distribution along the chord length in the YX plane and along the wingspan. The aerofoil wing is parameterized in three sections along the wingspan i.e. fuselage,

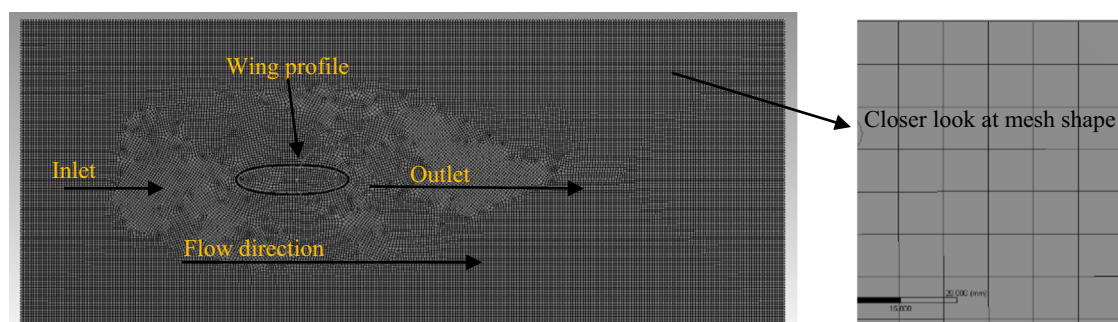


Fig. 2. Computational domain mesh.

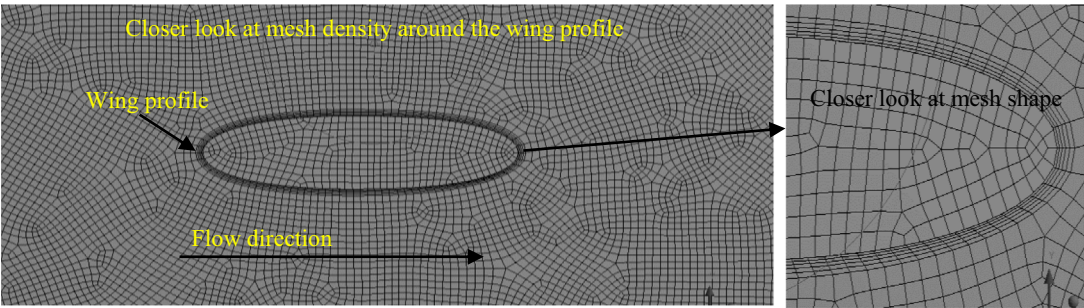


Fig. 3. The detailed mesh view around modified glider wing.

Table 3
Summarized version of the grid generation.

Mesh generation and Quality					
Mesh Method	Mesh density	Computational time	Aspect ratio	Skewness	Orthogonal Quality
Multi-zone	635,256	2hrs/1000 iteration	1	1.5072e-005	0.62

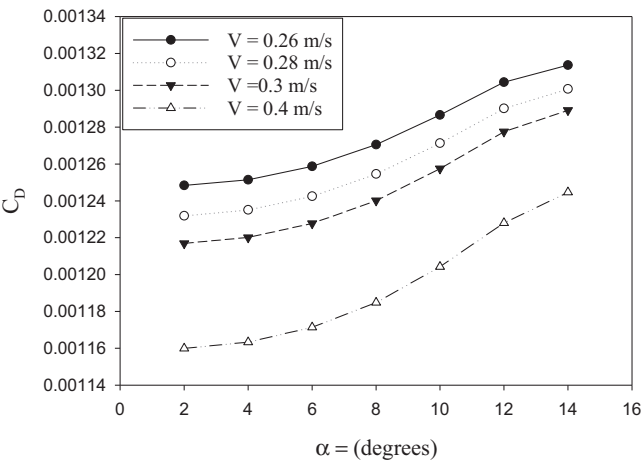


Fig. 4. Drag coefficient as a function of the AOA (α) at different inlet velocities.

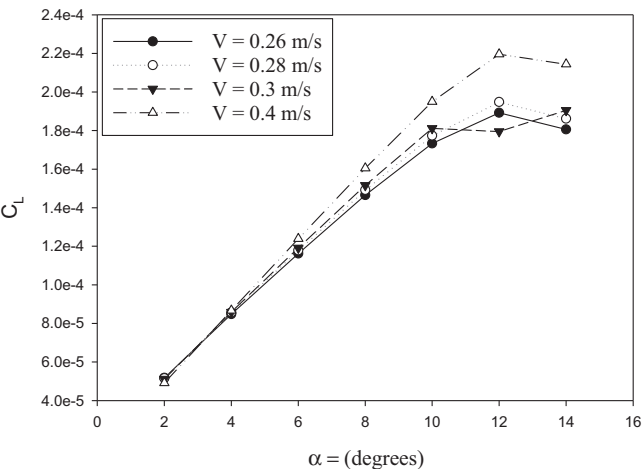


Fig. 5. Lift coefficient as a function of the AOA inlet velocities.

mid-span, and tip-wing. The pressure coefficient decreases sharply along the wingspan and the chord length. This behavior is consistent in all three locations analyzed. This behavior is in agreement with the previous experimental findings [5,7,11,19].

The surface distribution of pressure coefficient at different inlet velocities along the chord length in the YX plane is presented in Fig. 7. The profile of the pressure coefficient versus velocity curves is similar to those observed in Fig. 6. The 0.1 m/s velocity has a similar maximum value of C_p in all three sections of the wing whereas velocities higher than 0.1 m/s have different maximum values of C_p .

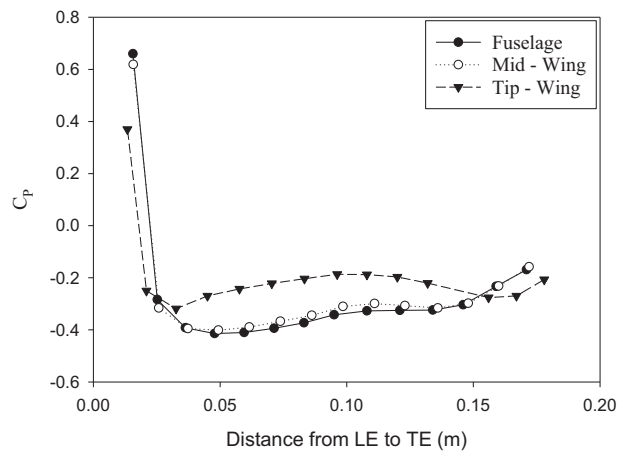
Fig. 8 (a) shows the drag polar performance at different AOA and different inlet velocities. The results show that inlet velocities have a significant impact on the C_d and C_l . Fig. 8 (b) shows the C_l/C_d ratio as the function of the AOA varies with inlet velocities. It is observed that for both Fig. 8 (b) and Fig. 7(a), the critical AOA of attack is approximately 12° . Fig. 8 (c) shows how the C_l/C_d ratio as the function of speed varies with the different AOAs. It can be seen from the Fig. 8 that the gradual increase in C_l/C_d ratio with the inlet velocities is recorded at higher angles of attack.

4. Limitations and future scope of the work

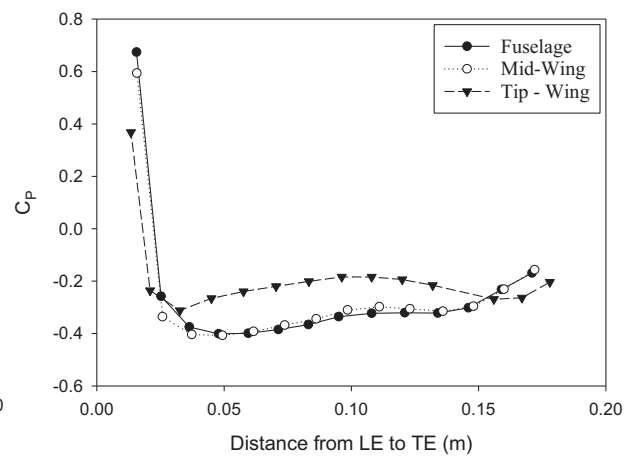
This work was limited to the modification of the wing profile of the underwater glider not the whole glider. The focus of this work was more on the trailing edge of the glider wing. The future work can incorporate the modification of the wing and also analyze the performance of the whole glider. The experimental analysis is recommended as the future plan for this study and this will assist with the comparative analysis.

5. Conclusion

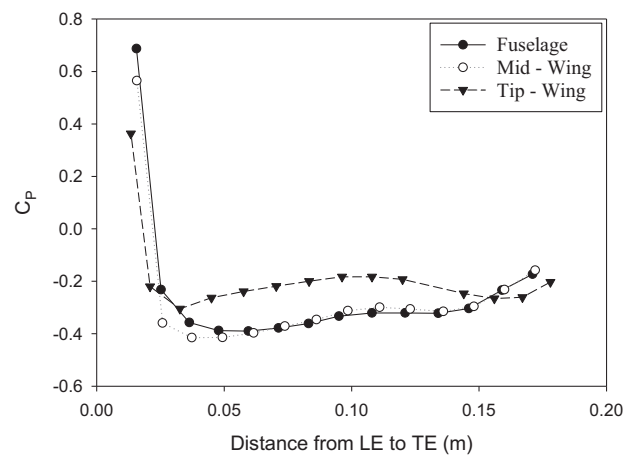
The hydrodynamic analysis was performed on the round trailing edge wing model of the underwater glider. The main focus was to analyze the lift and the drag coefficients against velocities and the angle of attack. In analyzing different aspects of the wing performance, the following conclusions were drawn:



(a)



(b)



(c)

Fig. 6. Pressure coefficient in YX plane (a) Fuselage, (b) Mid-span, (c) Tip-wing at fixed inlet speed of 0.3 m/s for AOA = 2, 6 and 10°

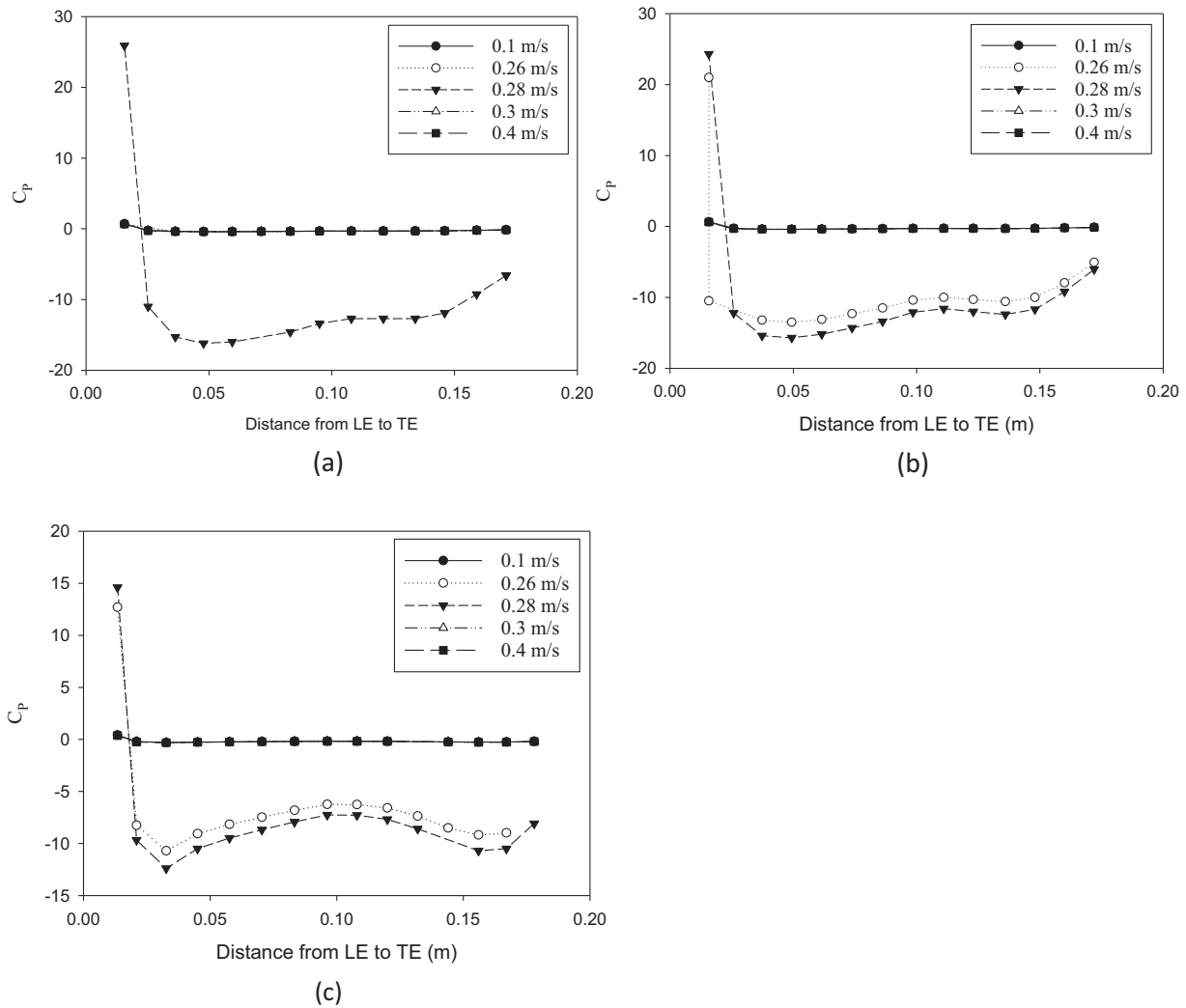


Fig. 7. Surface Distribution of the pressure coefficient at different inlet velocities along the YX plane at (a) Fuselage, (b) Mid-span, (c) Tip-wing for AOA being 2° .

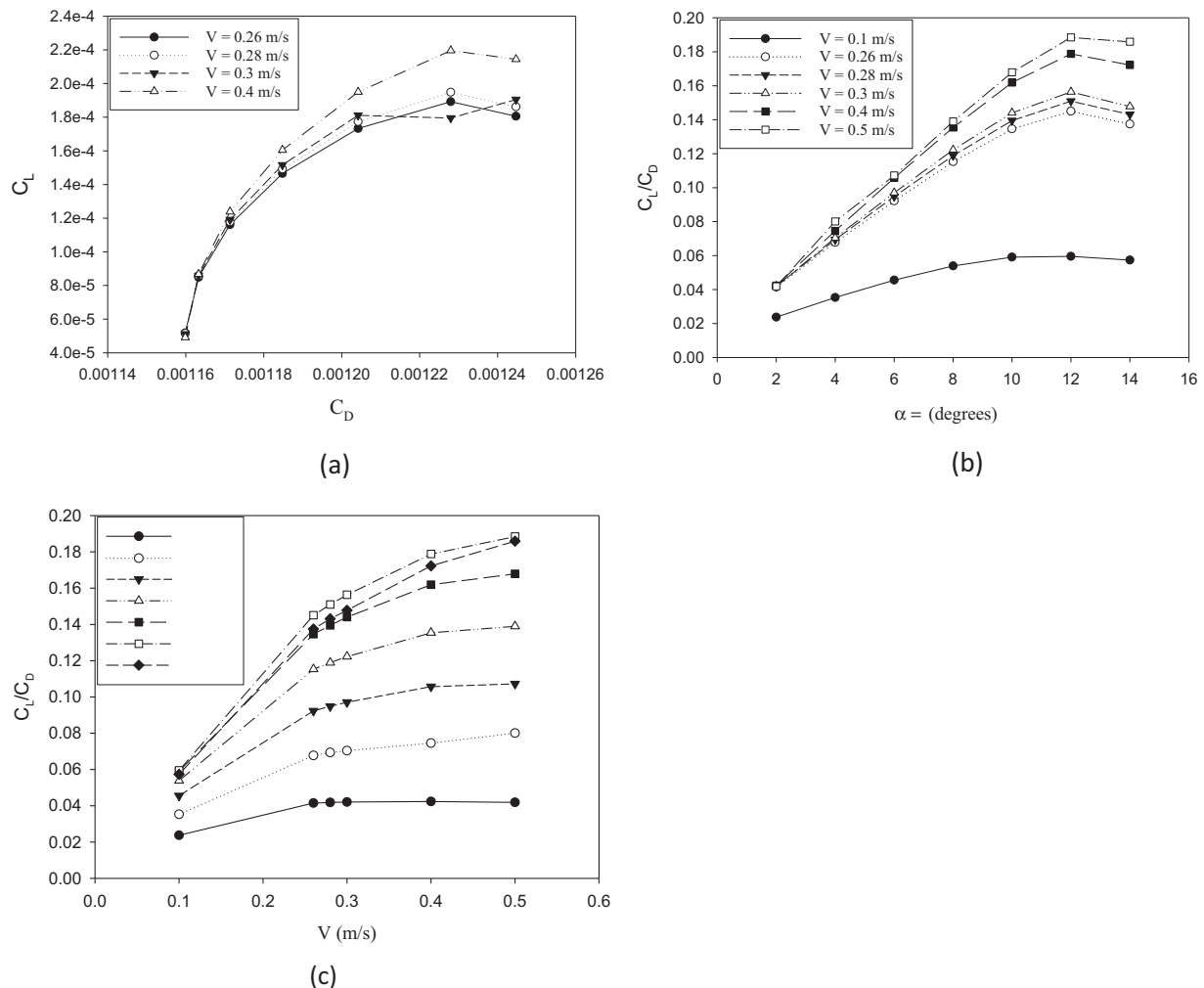


Fig. 8. The graph shows YX plane (a) Drag polar for different inlet speeds (C_L vs C_D) (b) C_L/C_D vs AOA (c) C_L/C_D vs speed.

- The performance of the underwater glider showed a strong dependence on the AOA and free stream velocities as these parameters showed a strong correlation with lift and drag coefficients.
- The investigation also showed that the optimal design point of the AOA is 12° at the corresponding speed of 0.26 m/s and this matched with the critical AOA of 12° .
- The results showed that C_p is higher closer to the fuselage and decreases towards the mid and the tip of the wing. This suggests that the wing experience more stress close to the fuselage than the rest of the wingspan. This, therefore, explains why more structural rigidity must be provided in this region of high stress concentration.

CRediT authorship contribution statement

Luyanda M. Meyers: . **Velaphi Msomi:** Conceptualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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