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Numerical Study of the Effect of Wing Position on Autonomous Underwater Glider

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ABSTRACT

Autonomous underwater gliders are a class of underwater vehicles that transit without the help of a conventional propeller. The vehicle uses a buoyancy engine to vary its buoyancy and with the help of the wings attached executes its motion. The hydrodynamic characteristics of the vehicle affect the longitudinal and turning motion. This paper discusses the effect of the wing's position on the vehicle's lift and drag characteristics. Computational fluid dynamics (CFD) tool is used to estimate the lift, drag, and pitching moment coefficients of the vehicle. The numerical methodology is validated using flow over NACA0012 wing results for low Reynolds numbers, and the results of CFD are discussed for possible application in estimation of glider motion.

Keywords: Glider; Turning; Spiral path; Helical path; Wings; Position; CFD; STARCCM+

NOMENCLATURE

AUG	Autonomous underwater glider
HDC	Hydrodynamic coefficients
C_L	Coefficient of lift force
AVG	Average
C_D	Coefficient of drag force
C_M	Pitching moment coefficient about axis passing through nose of glider
L/D	Lift / Drag ratio
α	Angle of attack
AoA	Angle of attack

1. INTRODUCTION

The study of water bodies like oceans, seas, rivers, and lakes historically was undertaken using instruments lowered from marine surface platforms. Autonomous underwater gliders have provided an alternative technological solution with high endurance that is cheaper and more efficient due to the usage of change in buoyancy in conjunction wings for propulsion[1]. Various studies have brought out the importance of Autonomous underwater gliders (AUGs) in the oceanographic field[2].

The vision for an underwater coastal surveillance network was discussed by Bahl[3]. The paper envisaged an omnipresent surveillance methodology with round-the-clock coverage. The Comprehensive Ocean Area Surveillance Technology (COAST) would include several low-cost under-sea sensor platforms called Bi-directional Instrumented Remote Device (BIRD). The underwater glider can be proposed to be a candidate for BIRD platform. Review on the applicability of underwater gliders for defence scenario was brought out by Ray[4], *et al.* Thus, the study of underwater gliders is of importance and is of increasing interest to the nation.

The manoeuverability studies of underwater gliders have been extensively researched since Leonard and Graver[5]. The traditional glide paths possible for an AUG are the sawtooth motion and the spiraling motion. Nina Mahmoudian brought out the similarities of Glider's motion to the Dubin's Car problem and highlighted the importance of turning motion as one of the essential aspects in the manoeuverability of the glider[6]. Further, a comprehensive list of basic and advanced flight paths available for an AUG was studied by Ziaeefard, and it was noted that all the advanced flight paths are a concatenation of the sawtooth and spiral paths[7].

The radius of the spiral path of a glider is one of the parameters in estimating the turning ability of the AUG. Other parameters include: the vehicle attitude during the turning motion and the speed of the turn. A glider with a smaller turning radius thus can be used for vertical profiling of channels and collection of data in lakes. Further, hovering motion, which cannot be achieved unless thrusters are there in underwater vehicles, can be recreated using smaller turning motions. Study of gliders in presence of oceanic currents is also being studied for path prediction[8].

A previous review undertaken by the authors discussed the importance of the spiral path and its characteristics[9]. One of the conclusions of the study was the gap in the literature regarding the effect of hull form on the turning trajectory of gliders. Further, a numerical code was developed for predicting the turning radius of gliders[10]. The inputs required for estimating the turning ability include the hydrodynamic coefficients (lift, drag, side force and roll, pitch and yaw moment coefficients)

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of the glider. Thus, the effect of HDCs on the glider motion characteristics is important. The current study is an attempt to understand the numerical effect of change in position of the wings of the gliders on the lift, drag force coefficients and the pitching moment coefficient. These coefficients can then be incorporated in the dynamics equations used for predicting the glider spiral path. The results can then be used to comment on the wing position for a glider vis-à-vis the role of the vehicle.

2. LITERATURE REVIEW

Essentially, the lift and drag characteristics of underwater gliders are affected by the geometric parameters of the vehicle's components such as wings, fuselage, and rudder. Further, the drag and lift force participation over these components also vary. Figure 1 brings out the distribution of Lift and Drag force as brought by Ting[11], *et al.* for a shallow water underwater glider[11] for various angles of attack (AoA). It is understood that wing accounts for more than 60 per cent of the lift force and 20 per cent of the drag is developed by a glider.

Similar findings were published by Singh[12] for a laboratory-based underwater glider. Hence, in studying the lift performance of the vehicle, a study of wings becomes necessary. The L/D ratio of the glider, with various configurations of the wing can indicate the effectiveness of the glider. Further, force coefficients C_L and C_D for various wing configurations can be used to predict the spiral path of those gliders.

Effect of wings on underwater gliders have been subject of study of a multitude of researchers. The study of flow across aerofoil sections at low Reynolds number (order of 10^4-10^5) is of interest for the glider due to the typical lengths and velocity scales. Ebata[13] studied the aerodynamic characteristics for various aerofoils of underwater gliders at low Reynolds number with the help of towing tank experiments and CFD studies. They brought out that the L/D ratio of aerofoils with camber become larger than those of flat plate. Further, the effect of maximum camber ratio and maximum camber position and thickness ratio on aerodynamic characteristics and optimum cross-sectional shape of the wing for underwater glider were found using numerical analysis. The authors proposed that NACA 7302 is an ideal cross-section for a higher L/D ratio requirement. However, the emphasis of the study was only on the wing sections with fixed aspect ratios and fixed-wing position.

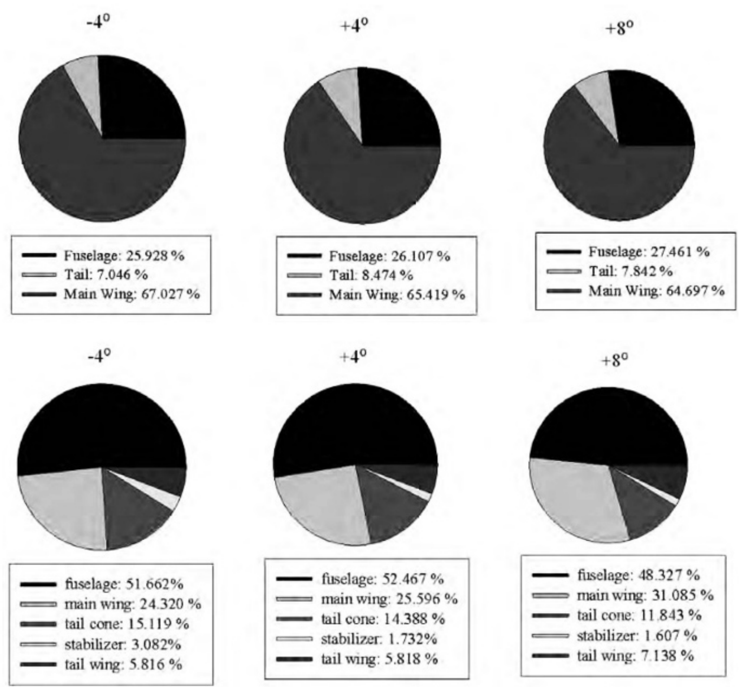


Figure 1. Lift and drag force distribution of an underwater glider[11].

Study of airfoil characteristics for various Reynolds number regime has also been undertaken in the past by many authors. The studies referred to for this paper are works of Winslow[14] and Malik[15].

Javaid[16] studied the effect of change of aspect ratio of wings on the glider stability and glide path characteristics using experimental and numerical methods. The authors considered two type of wings, rectangular and tapered, and they summarised that the rectangular wing had better dynamic stability and higher Lift force developed. The authors also studied the spiral turning radius of both the gliders and concluded that turning radius of the vehicle with rectangular wings will be lesser compared to a vehicle with tapered wing form[17]. This was proposed by taking the lift force developed by the vehicles to be inversely proportional to the radius of the turn (as brought out earlier).

Fan & Woolsey[18] studied and published the elements of underwater glider performance and stability using analytical methods. The authors studied geometric parameters of the vehicle and characterised the slenderness of the hull, and position and shape of the wing. In this regard the salient conclusions brought out by the authors are as:

(a) For a glider of fixed mass and buoyancy capacity, higher speeds can be attained using longer hull lengths, smaller wingspans, larger hull fineness ratios, and higher wing aspect ratios.
(b) To maximise the L/D ratio at a given minimum glide angle speed, on the other hand, one should decrease the hull length and increase the wingspan ratio.
(c) Farther aft the wing is located, the more stable the longitudinal glider dynamics become, due to the increased pitch damping.

Liu[19], *et al.* undertook a study of comparison of the position of wings on a glider and its effect on L/D. The study was undertaken for one angle of attack (4 degrees) at a velocity of 0.5 m/s for a hybrid underwater glider. It was brought out that axial position variation of the wing has a negligible effect on L/D. However, the glider, as an unmanned vehicle, can take steeper glides at higher angles of attack. Hence, a study to understand this effect of axial position change, on a spectrum of angles (-8 to +8 degrees) of attack and velocity is deemed necessary.

Guggilla[20], *et al.* studied a candidate glider with varying wing sections. The sections compared were flat plate wing and NACA0012 wing. The authors brought out that NACA0012 wing section had better L/D performance. Further, hydrodynamic characteristics of blended wing glider were studied by the authors[21]. The blended wing glider is the next version to the legacy glider (Slocum, Spray, etc.) and has been found to exhibit very high L/D efficiency compared to legacy gliders. In this paper, legacy glider configuration is taken as candidate glider.

3. CURRENT STUDY

The literature review brought out the gap in understanding the effect of wing position on the glider HDCs. It was opined that existing and proven methodology of CFD methods could be used in estimating the lift and drag coefficients of the glider and by varying the wing position, one can observe the changes in these coefficients to comment.

To understand the effects of the positioning of the wing on the glider, a prototype model was developed based on previous studies. The characteristics of the candidate glider selected are as shown in Table 1.

Table 1. Characteristics of the candidate glider

Particular	Value
Length	1.26 m
Wingspan (each)	0.55 m
Wing chord	0.134 (mean)
Rudder chord	0.04 m
Rudder span	0.05 m
Wetted surface area	0.7515 m^2
Diametre	0.140 m

As shown in Fig. 2, a NACA 0012 section has been selected for wings and rudder. The wing is a tapered wing with outer most chord length being 0.1 m and the inner chord length being 0.169 m.

3.1 Methodology for CFD study

The methodology adopted in this study is as:

(a) Lift and drag forces developed on NACA0012, are calculated using numerical methods and compared with published results of Winslow for validation of CFD methodology[14].

(b) The wing section position is varied in three variants (as shown in Fig. 1), and comparison of performance characteristics of the glider is undertaken.

A NACA0012 wing of chord length has been initially selected for validation studies. The chord length of the airfoil is 0.055 m (denoted as Xa) and aspect ratio of 4. The computation domain and the boundary conditions were taken as shown in Fig. 3. A RANSE solver with SST Menter K-ω turbulence model has been used. A grid independence study was undertaken with surface remesher, prism layers and polyhedral meshing models in StarCCM+. The minimum number of cells after which the values do not change was found to be 10^6 cells. The study is undertaken to assess the C_L and C_D of the wing section concerning the change in Angle of Attack (α). α is varied from 0 degrees to + 12 degrees for Reynolds number of 4.31E04.

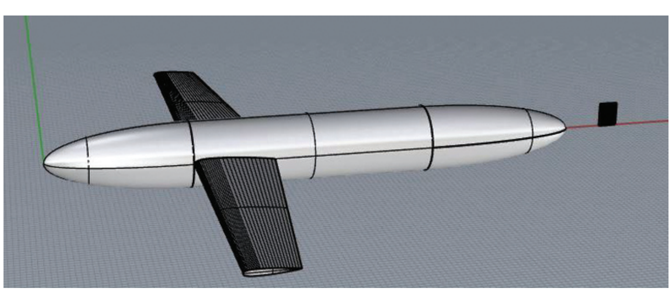


Figure 2. Candidate autonomous underwater glider.

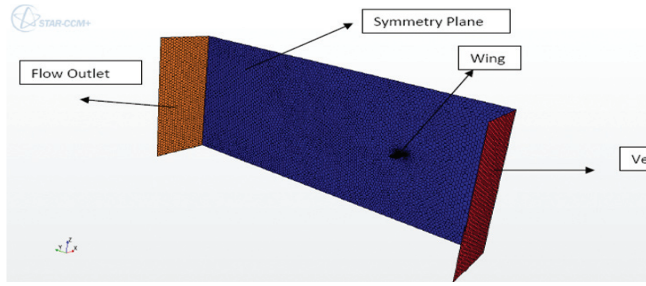


Figure 3. Boundary conditions for the study of NACA0012 wing.

The values of lift and drag coefficient are compared with published experimental results of Ohtake[22], *et al.* and plotted in Fig. 4. The estimated values of C_L display the trend of experimental data and percentage mean square error was estimated to be 9 per cent.

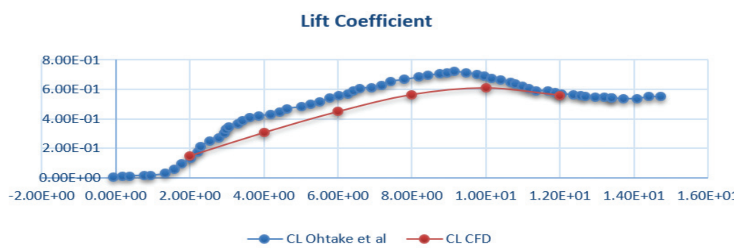


Figure 4. Lift Coefficient (on y-axis) *vs* AoA in degrees (on x-axis).

3.2 Study of Variation of Wing Position

The candidate glider was modelled in CAD software, and three variants or versions were developed as shown in Fig. 5. The wing aspect ratio and section were kept constant. The position of the wing was changed from forward to aft. Investigation of C_L and C_D on these models with a change in the angle of attack (range -8 to +8 degrees) for five velocities (range 0.1 to 0.5 m/s) was undertaken. The position of the wing from nose of the glider is 308 mm for Version 1, 469 mm for Version 2, and 638 mm for Version 3.

3.2.1 Details of CFD Model

The domain dimensions used for the study are taken as per ITTC recommendations for marine CFD applications[23]. Here

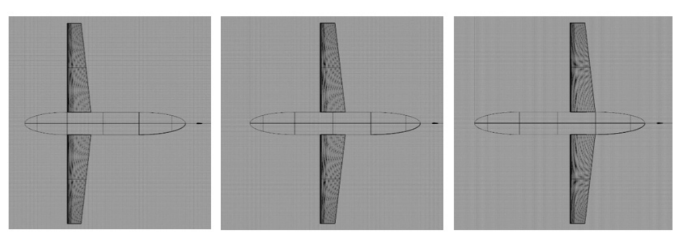


Figure 5. Three versions of the AUG with different wing position (Version 1 to 3 left to right).

L_G is the length of the glider, L_{FWD} is $1.3L_G$, and L_{AFT} is $5L_G$. The side wall domain distance is also taken as 1.3 L_G. Boundary conditions are also shown in Fig. 6. A 3D, steady flow was chosen for CFD study. The mesh size was reduced by meshing only one half of the domain and assigning symmetry boundary condition to the middle plane (Fig. 7). This was undertaken as the body was axisymmetric, and the study involved a change in the angle of attack alone. Grid independence study was undertaken, and the results are also placed in Fig. 7. The number of cells was found to be 1.6 million. The meshing models used involve polyhedral meshes with prism layers calculated as five layers with a stretching factor of 1.5. The total boundary layer thickness was calculated to be 6.8E-4 m using blasius formulation. The Reynolds number of the flow varies from 1.4E05 to 7.1E05. SST (Menter) K-ω turbulence model was chosen with a grid point for the first cell at $y^+<1$. This model was found to predict flow characteristics near the wall with better accuracy compared to other models as per literature[12].

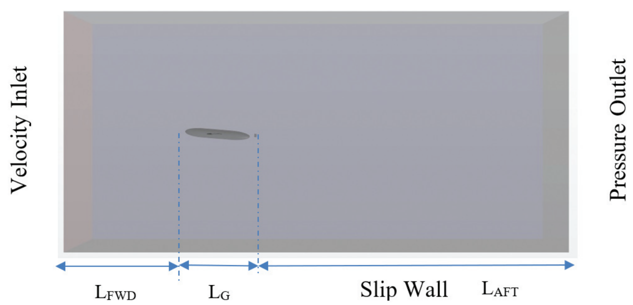


Figure 6. Domain details and boundary conditions.

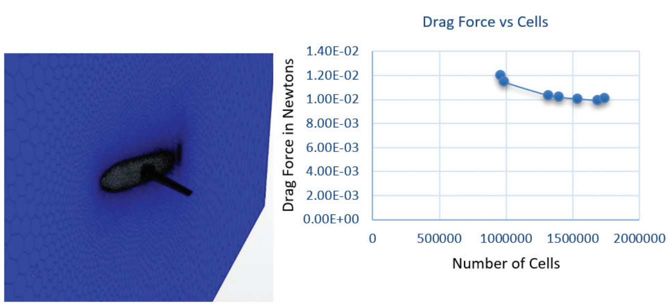


Figure 7. View showing mesh of glider, symmetry plane and grid independency study.

4. RESULTS AND DISCUSSION

The L/D ratio for all three versions of candidate glider that was estimated by CFD are plotted in Fig. 8. The trend of L/D is found to be similar. For ease of comparison, the lift and drag coefficients for each variant are plotted by averaging them (for C_L and C_M) and obtaining the RMS value (for C_D) against the angle of attack. These graphs are placed in Figs. 8 and 9. C_M is calculated from reference point at nose of glider.

Analysis of results shown above brings out the following conclusions:

- For individual versions, the drag coefficient value decreases with an increase in velocity, and lift coefficient increases with an increase in velocity.
- Version 3 (wing position farther aft) has the maximum lift and minimum drag characteristics.

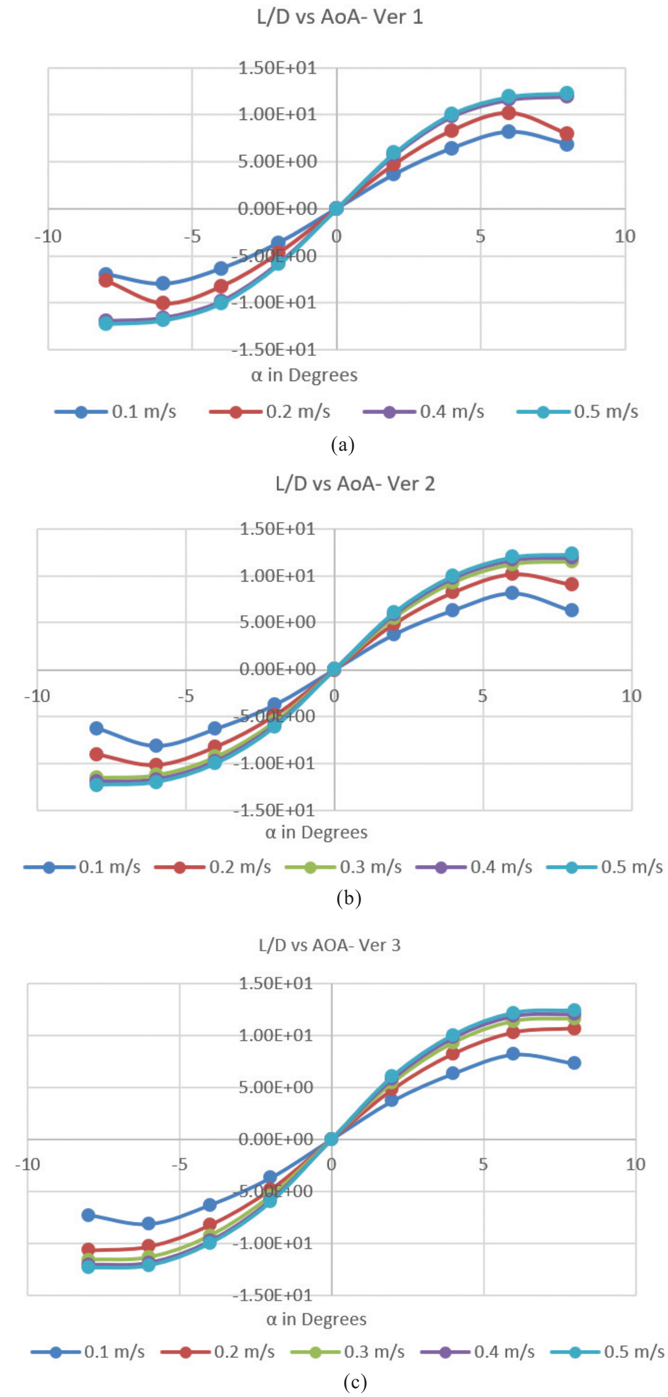
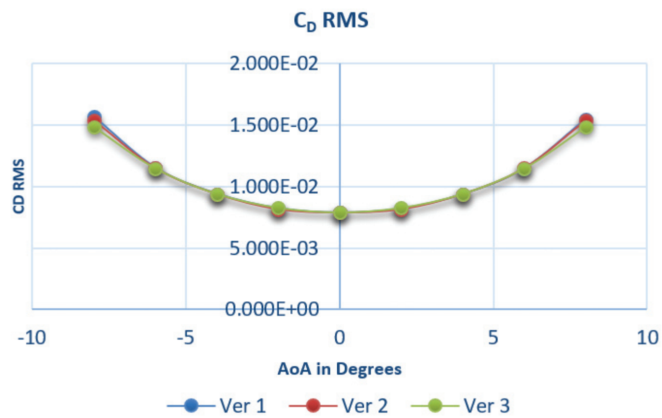
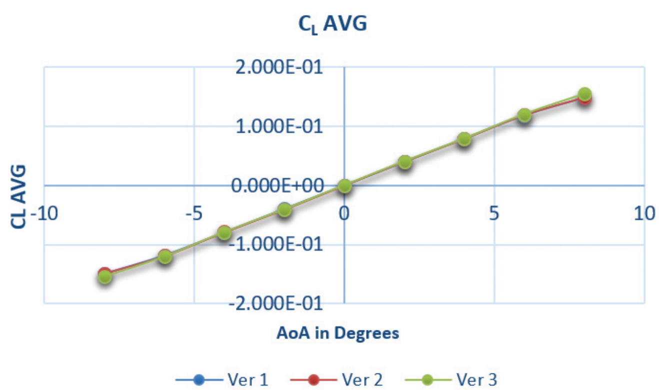


Figure 8. Lift/ Drag Ratio for three versions w.r.t α (in degree) on x-axis.

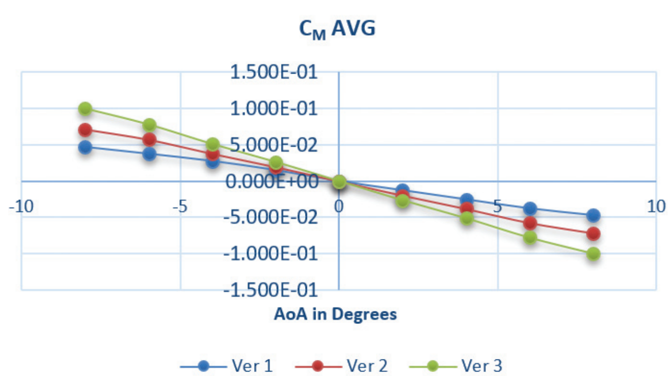
- Version 1 (wing position at the forward of the vehicle) has the lowest lift characteristics and highest drag characteristics among the three variants of candidate glider. The lift coefficient difference between version 1 and 3 is about 3 per cent.
- The pitching moment coefficient has a higher percentage difference for three variants with the highest values going up to 50 per cent (between variant 1 and 3). Version 3 has the highest C_M values, and Version 1 has the lowest.
- Lift/Drag ratio values for all three versions follow a similar trend with not much difference for lower angles



(a)



(b)



(c)

Figure 9. C_D RMS, C_L Average and C_M Average *vs* AoA (in Degrees) on x-axis for three versions.

of attack. This result matches the published results for hybrid underwater gliders for lower angles of attack[19]. However, the percentage difference between average L/D values of version 1 and 3 is found to be as high as 6 per cent (as shown in Table 2) for higher angles of attack.

- Absolute values of L/D for the three versions for the five velocities studied is as shown in Table 3. This gives us an insight that version 1 and 2 do not exhibit much change, but version 3 has a better L/D performance throughout.
- Average and RMS values are calculated to enable plotting of trend line for three values. This trend line can then be used to generate hydrodynamic coefficients. For example, the trend line of C_L average for version is $C_L = 0.0192\alpha - 5E\text{-}05$. Thus $C_{L\alpha} = 0.0192$ and $C_{L0} = 5E\text{-}05$. Similarly, C_D and C_M trend lines can be estimated, and HDCs can be estimated. These values can be used as inputs for estimating the spiral path characteristics[24,10].
- An estimate of the turning radius of the glider was discussed by Javaid[17] wherein the lift force developed by the vehicle, was used for this purpose and inversely proportional to the radius of turn. Thus, a vehicle with higher lift force will perform a tighter turn, and it can be estimated that version 3 will have a smaller turning radius compared to other versions.

Table 3. Comparison of L/D for various velocities at higher AoA

Velocity (m/s)	AoA (degree)	L/D (Ver 1)	L/D (Ver 2)	L/D (Ver 3)
0.1	6	8.16	8.15	8.17
	8	6.85	6.26	7.31
0.2	6	10.2	10.2	10.3
	8	7.94	9.02	10.7
0.3	6	11.1	11.2	11.4
	8	11.5	11.5	11.6
0.4	6	11.6	11.7	11.9
	8	12	11.9	12.1
0.5	6	11.9	11.7	12.2
	8	12.3	11.9	12.4

Table 2. Comparison of average L/D for three versions

AOA (degree)	L/D Ver 1	L/D Ver 2	L/D Ver 3	Percentage diff- 1&2	Percentage diff- 2&3	Percentage diff- 1&3
-8	-10.067	-10.196	-10.798	1.258	5.576	6.764
-6	-10.537	-10.643	-10.768	0.999	1.158	2.145
-4	-8.761	-8.726	-8.727	-0.399	0.012	-0.388
-2	-5.060	-5.217	-5.156	3.009	-1.196	1.849
2	5.077	5.217	5.156	2.689	-1.196	1.525
4	8.781	8.726	8.727	-0.630	0.012	-0.618
6	10.598	10.643	10.768	0.420	1.158	1.572
8	10.103	10.196	10.798	0.904	5.576	6.430

5. CONCLUSION AND WAY AHEAD

The current study brings out that positioning the wings of the glider at the farthest point aft improves the performance of the vehicle but the increase is very small and visible at higher angles of attack. Further, with the knowledge of turning radius dependence on the HDCs, the results obtained from this study can be incorporated to assess the turning radius for the vehicle. The positioning of wings in the aft, as brought out in the literature review is beneficial for longitudinal motion of the glider and also for the stability in that motion[18].

However, for quantifying and predicting all the spiral path characteristics of the glider, which include vehicle attitude, turning speed, etc. the established method of solving the dynamics equations, will be necessary. For such analysis, all hydrodynamic coefficients of the vehicle will need to be estimated, which include side slip coefficients, rotatory coefficients, and added mass and moment of inertia of the vehicle. The effect of the wing position on these coefficients has not been undertaken and will be taken up as future work.

Such an analysis will require a CFD study of the glider using a domain with curvature[25]. Further, the experimental validation of such turning characteristics is also necessary. This is intended to be undertaken in the future using towing tank and pool based studies of a laboratory glider.

REFERENCES

1. Davis, R.; Eriksen, C. & Jones, C. Autonomous buoyancy-driven underwater gliders. *In*Technology and applications of autonomous underwater vehicles, edited by Griffith, G. CRC Press, Florida, USA, 2010. pp. 37-58.
doi: 10.1201/9780203522301.ch3
2. Suberg, L; Wynn, R.B.; Kooij, J. van. der.; Fernand, L.; Fielding, S.; Guihen, D.; Gillespie, D.; Johnson, M.; Gkikopoulou, K.C.; Allan, I.J.; Vrana, B.; Miller, P.I.; Smeed, D. & Jones, A.R. Assessing the potential of autonomous submarine gliders for ecosystem monitoring across multiple trophic levels (plankton to cetaceans) and pollutants in shallow shelf seas. *Methods Oceanogr*., 2014, **10**,70-89.
doi: 10.1016/J.MIO.2014.06.002
3. Bahl R. Vision for Comprehensive Ocean Area Surveillance Technology (COAST). *In* Proceedings of National Symposium on Acoustics (NSA-97), Visakhapatnam, 1997.
4. Ray, A; Singh, S.N. & Seshadri, V. Underwater gliders - force multipliers for naval roles. *In*Proceedings of RINA, Warships 2011 Naval Submarine UUVS, London 2011.
5. Leonard, N.E. & Graver, J.G. Model-based feedback control of autonomous underwater gliders. *IEEE J. Oceanic Eng*., 2001, **26**(4), 633-645.
doi: 10.1109/48.972106
6. Mahmoudian, N; Woolsey, C.A. & Geisbert, J. Steady turns and optimal paths for underwater gliders. *In* Collection of Technical Papers - AIAA Guidance, Navigation, and Control Conference 2007, 2007, **3**, 2643-2655.
7. Ziaeefard, S. Extending maneuverability of internally actuated underwater gliders, an attempt to develop an open platform for research and education. Michigan Technological University, Michigan, 2018. (PhD Thesis)
8. Gautam, U. & Ramanathan, M. Simulation for path planning of SLOCUM glider in near-bottom ocean currents using heuristic algorithms and Q-learning. *Def. Sci. J*., 2015, **65**(3), 220-225.
doi: 10.14429/dsj.65.7855
9. Rayaprolu, V.S. & Rajagopalan, V. Maneuverability and dynamics of autonomous underwater gliders: Study and review of the spiral path maneuver. *Trans. R Inst. Nav. Archit. Part B – Int. J. Small Cr. Technol*., 2019, **161**(B2), 1-15.
doi: 10.3940/rina.ijsct.2019.b2.225
10. Rayaprolu, S.S & Rajagopalan, V. Effect of rudder and roll control mechanism on path prediction of autonomous underwater gliders. *In* Proceedings of the International Conference in Ocean Engineering, Springer, Chennai, 2018.
doi: 10.1007/978-981-13-3119-0_29
11. Ting, M.C.; Mujeebu, A.M.; Abdullah, M.Z. & Arshad, M.R. Numerical study on hydrodynamic performance of shallow underwater glider platform. *Indian J. Mar. Sci*., 2012, **41**(2),124-133.
12. Singh, Y.; Bhattacharyya, S.K. & Idichandy, V.G. CFD approach to modelling, hydrodynamic analysis and motion characteristics of a laboratory underwater glider with experimental results. *J. Oceanic. Eng. Sci*., 2017, **2**(2),90-119.
doi: 10.1016/j.joes.2017.03.003
13. Ebata, S.; Yasuda, T.; Minagawa, H.; Miyamoto, Y. & Satofuka, N. A Study of cross-sectional shape of wing for underwater glider at low reynolds number region. *Trans JAPAN Soc. Mech. Eng. Ser. B*., 2013, **79**(806),1886-1899 (Japanese).
doi: 10.1299/kikaib.79.1886
14. Winslow, J.; Otsuka, H.; Govindarajan, B. & Chopra, I. Basic understanding of airfoil characteristics at low reynolds numbers. *Journal Aircraft*, 2017, **55**(3),1050-1061.
doi: 10.2514/1.c034415
15. Malik, K.; Asrar, W. & Sulaeman, E. Low Reynolds number numerical simulation of the aerodynamic coefficients of a 3D wing. *Int. J. Aviat. Aeronaut. Aerosp*., 2018, **5**(1).
doi: 10.15394/ijaaa.2018.1209
16. Javaid, M.Y.; Ovinis, M.; Hashim, F.B.M.; Maimun, A.; Ahmed, Y.M. & Ullah B. Effect of wing form on the hydrodynamic characteristics and dynamic stability of an underwater glider. *Int. J. Nav. Archit. Ocean Eng*., 2016, **9**(4), 382-389.
doi: 10.1016/j.ijnaoe.2016.09.010
17. Javaid, M.Y.; Ovinis, M.; Thirumalaiswamy, N.; Hashim, F.B.M.; Maimun, A. & Ullah, B. Dynamic motion analysis of a newly developed autonomous underwater glider with rectangular and tapered wing. *IJMS.,* 2015, **44** (12), 1928-1936.
18. Fan, S. & Woolsey, C. Elements of underwater glider performance and stability. *MTS* 2012, **47**(3), 81-98.
doi: 10.4031/MTSJ.47.3.4
19. Liu, F; Wang, Y; Niu, W; Ma, Z. & Liu, Y. Hydrodynamic

performance analysis and experiments of a hybrid underwater glider with different layout of wings. *In*OCEANS 2014 - *TAIPEI*, IEEE, Taipei, 2014. doi: 10.1109/OCEANS-TAIPEI.2014.6964512

20. Guggilla, M. & Rajagopalan, V. Study on the hydrodynamic performance of unmanned underwater glider with varying wing section using CFD. *In* Proceedings of MARHY 2018, Madras. 2018,1-8. http://www.doe.iitm.ac.in/vijay2028/publications/. (Accessed on 27 June 2019).
21. Guggilla, M. & Rajagopalan, V. CFD study of the hydrodynamic characteristics of blended wing unmanned underwater gliders. *In* The Twenty-Ninth International Ocean and Polar Engineering Conference. Honolulu, Hawaii, 2019.
22. Tomohisa, O.; Yusuke, N. & Motohashi, T. Nonlinearity of the aerodynamic characteristics of NACA0012 aerofoil at low reynolds numbers. *J. Japan Society Aeronaut. Space Sci.,* 2007, **55**(644), 439-445. doi: 10.2322/jjsass.55.439
23. Practical guidelines for ship CFD applications, *In* International Towing Tank Conference (ITTC) recommended procedures and guidelines*,* 2011.
24. Zhang, F.; Zhang, F. & Tan, X. Tail-enabled spiraling maneuver for gliding robotic fish. *J. Dyn. Syst. Meas. Control*., 2014, **136**(4), 041028. doi: 10.1115/1.4026965
25. Zhang, S.; Yu, J.; Zhang, A. & Zhang, F. Spiraling motion of underwater gliders: modeling, analysis, and experimental results. *Ocean Eng*., 2013, **60,** 1-13. doi: 10.1016/j.oceaneng.2012.12.023

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