EFFECT OF TRANSVERSE, LONGITUDINAL AND VERTICAL SEPARATION ON DRAG FOR A FLEET OF AUTONOMOUS UNDERWATER GLIDER

by

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Dissertation submitted in partial fulfilment of

the requirement for the

Bachelor of Engineering (Hons)

Mechanical Engineering

JANUARY 2016

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Dr. Mark Ovinis)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ARJUND A/L PRAKASAN

ABSTRACT

Land vehicle platooning has shown positive result in improving its fuel efficiency with decrease in drag. In this work, platooning of an autonomous underwater glider fleet is investigated. Specifically, the effect of transverse and longitudinal separation of the glider on the drag for a “V” formation is studied. An alternative 3D configuration for “V” formation which requires less foot print space is proposed. Besides that, the effect of transverse, longitudinal and vertical separation of glider for the 3D “V” formation on the drag will be studied. The number of glider in the fleet will be limited to five gliders. The project is a simulation study using ANSYS Fluent with Re-Normalization Group (RNG) k-epsilon model with non-equilibrium wall function as the turbulence model. Based on the simulation, the drag of the alternative 3D configuration is relatively similar to the drag of the drag of “V” formation. This shows that low drag can still be achieved with a more compact formation.

ACKNOWLEDGMENT

I would like to take this opportunity to express my gratitude to everybody involved in completing my Final Year Project. Thank you Dr. Mark Ovinis, FYP supervisor who have been guiding me for the duration of the project. Your advices have been most helpful.

Special thanks to Dr. Fakhruldin, internal examiner for his feedback during proposal defense and poster presentations and also Mr. Yasar whom I referred to regarding simulation matters.

Last but not least, thank you to my parents as well as siblings and Thulasi, who always motivate me and have given me their opinion when I need it the most. Their greatest support had played a major role in the completion of my final year project.

Table of Contents

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background Study

Underwater gliders are unmanned vessels which travels through the ocean by a series of diving and ascending movement that is performed by displacing its center of gravity through ballasting and de-ballasting. Gliders increased in demand are contributed to its energy efficiency and lowering of human life risk due to its capability of reaching location beyond human limit which allows critical data collection [1]. Besides that, a glider has an effective initial cost and low or negligible running costs [1] [2]. In the year of 1989, Henry Stommel envisioned a future usage of a platoon of underwater glider for oceanography purpose [3]. A platoon of underwater gliders will enable a greater coverage during an expedition [4] [5] [6].

Vehicle platooning is the arrangement of several vehicle in a specific formation. In platooning a vehicle typically a truck leads the way and is followed by another truck with a fixed distances. This method improves the fuel efficiency by reducing the drag or resistance due to the wind. This is due to the improved aerodynamics condition of the following vehicle which is covered by the leading truck. The fuel consumption efficiency increases as the distance between the vehicles reduces [7]. Platooning of land vehicle opens the possibility of platooning of underwater glider in the field of oceanography for data collection, sensing as well as research and development.

However, a single line platooning configuration of land vehicle is not feasible for underwater glider in the field of oceanography. The following gliders will experience lesser drag but the single line configuration are deemed to be redundant in the field of oceanography as the following glider will be surveying the same area that has been covered by the leading glider.

A study was conducted by Rattanasiri on three types of glider formation, namely parallel formation, echelon formation and "V" formation shows that separation distance between each glider in a fleet affect the drag of the glider fleet [8]. "V" formation is oriented on one plane where by only lateral and longitudinal separation are present. "V" formation are adapted from the bird flight formation as show in Figure 1.1.

Figure 1.1: Bird flight formation [9]

1.2 Problem Statement

While a "V" formation decreases the overall drag, it increases the overall foot print of the fleet. So how can the gliders be configured to reduce the foot print area. Besides that the effect of transverse, longitudinal and vertical separation of a glider in a fleet is not known.

1.3 Objectives

This project aims:

1. To determine an alternative "V" configuration which requires less foot print area.
2. To establish a correlation between transverse, longitudinal and vertical separation with the drag of the autonomous underwater glider fleet.

3. To determine separation distance with least amount of drag for the alternative “V” formation of autonomous underwater glider fleet.

1.4 Scope of Study

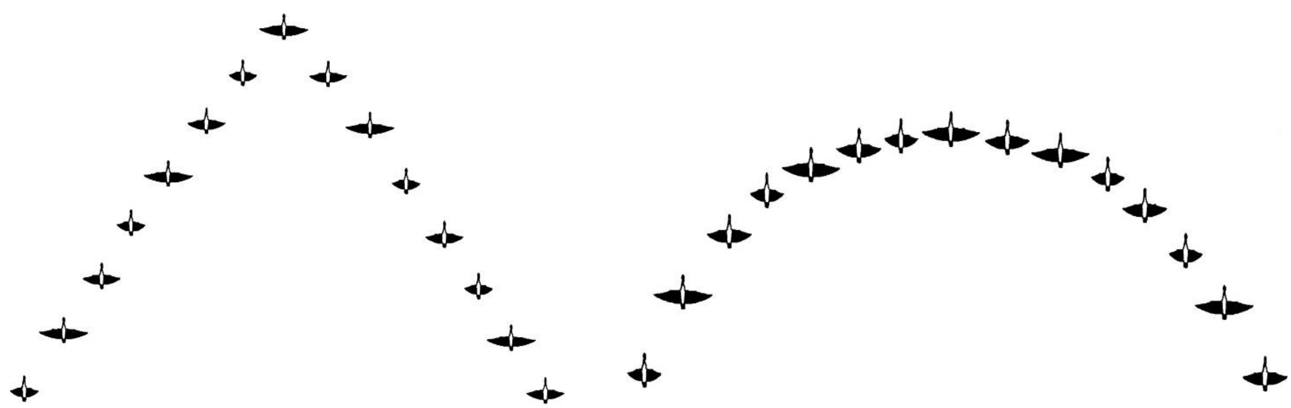
The project will be focused on the tubular shaped Autonomous Underwater Glider (AUG) such as *Slocum, Seaglider* and *Spray.* The study will be based on CFD analysis conducted using ANSYS Fluent. The number of glider for the simulation will be limited to five gliders. The flow field for the simulation acts in the horizontal direction only to represent the glider velocity. Ocean current and depth will not be considered in this project. The simulation will be focused on “V” shaped formation. The transverse and longitudinal separation will be limited to 1.1m while the vertical separation will be limited to one glider diameter.

CHAPTER 2

LITERATURE REVIEW

2.1 Bird Flight Pattern

The longitudinal and lateral separation of the birds affect the energy saving benefits from their flight formation. The trailing birds gain benefits from the wing tip vortices and uplift at the expense of the leading bird, but the leading bird can also gain some benefits when the longitudinal separation are shorter. Theoretically, when a birds wingtip overlaps laterally with preceding bird it will gain more benefits from the uplift [9]. Figure 2.1 (a) and (b) shows the “V” and bow flight formation of birds.



(a) (b)

Figure 2.1: (a) V flight formation of bird (b) bow shaped flight formation of bird [9].

2.2 Drag

Drag is the forces acting on a solid object in the direction of the relative fluid flow velocity. Drag forces depends on velocity. Typically there are two types of drag acting on a body in a flowing fluid, namely the pressure drag and skin friction drag.

The pressure drag refers to the opposing force acting on the body, it depends strongly on the shape of the body. The pressure drag occurs when a body is perpendicular to the flow. The skin friction drag, is the component of integral of the shear stresses and it occurs when the flow is parallel to the body surface [10] [11].

2.3 AUG Fleet Configuration

Study conducted by Rattanasiri have shown that platooning of the gliders improve their efficiency by reducing the drag. Positioning of individual glider affect the drag the other gliders. The drag is affected by both of transverse (S/L) and longitudinal (D/L) separation between each glider.

2.3.1 Parallel Formation

The AUG's are aligned parallel to each other as shown in Figure 2.2. The drag on both glider are relatively the same. With the increase in transverse distance (S/L), the drag reduces for both glider (9.9 % to 2 %). The drag is due to skin friction which is caused by flow between the gliders [8]

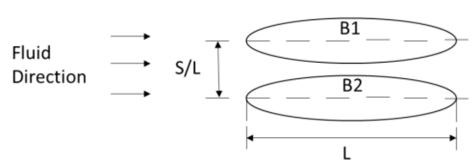


Figure 2.2: Parallel formation [8].

2.3.2 V Formation

Three gliders are configured in a "V" shape as shown in Figure 2.3. The drag of the leading glider B1 is much higher compare to the other two gliders, the drag is also relatively high compare to the parallel formation. The drag of B2 & B3 are similar to the drag of the glider with parallel formation [8]. At a constant transverse separation the overall drag of the fleet in a glider formation decrease with the increase in longitudinal point before the drag increase again.

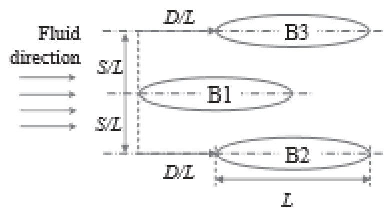


Figure 2.3: V formation [8].

2.3.3 Echelon Formation

Figure 2.4 shows the configuration of echelon formation. The drag of each glider reduces from B1 to B4. Pulling force was experienced by glider B3 as well as B4. Glider B2 experiences negligible drag while the leading glider experiences similar drag to that of a parallel formation [8]. The efficiency of individual following gliders improved except for the efficiency of the leading glider.

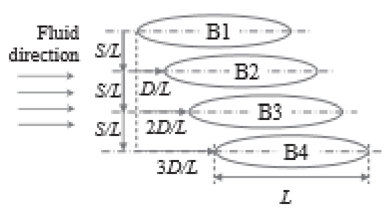


Figure 2.4: Echelon formation [8].

CHAPTER 3

METHODOLOGY

3.1 Flow Chart

The steps involved in conducting the project is represented in Figure 3.1.

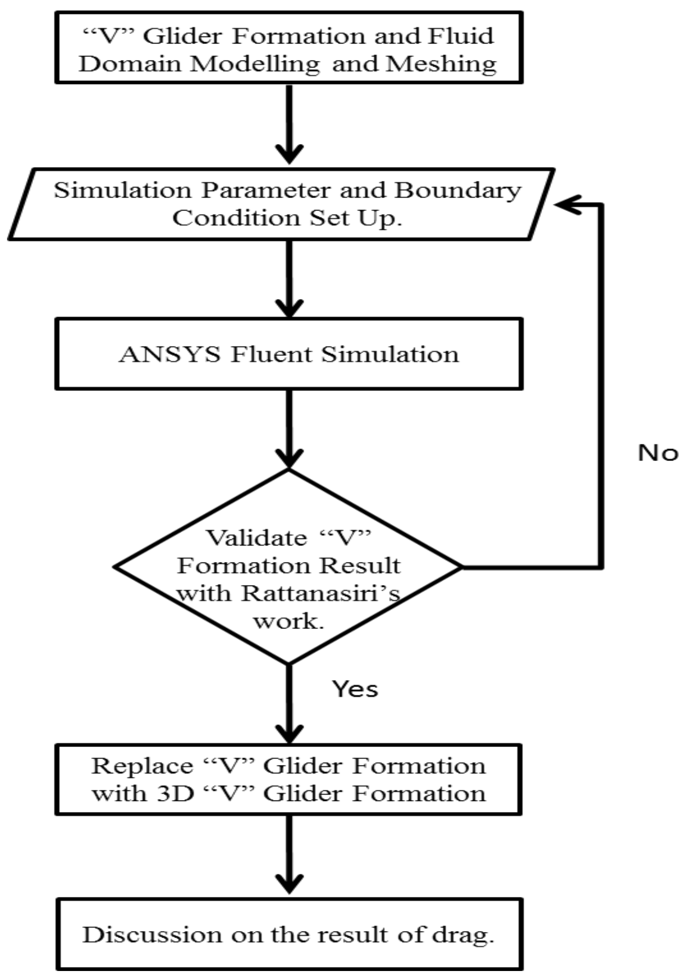


Figure 3.1: Flow Chart.

3.2 Detailed Description

3.2.1 Glider Model

The model should be able simple and able to depict the dynamic condition of the gliders. TheUTP glider model designed by Mr. Yasar, as shown in Figure 3.2 was used in this project as experimental results were available to validate the simulation model..

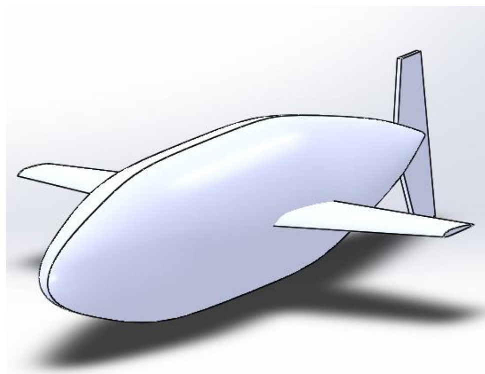
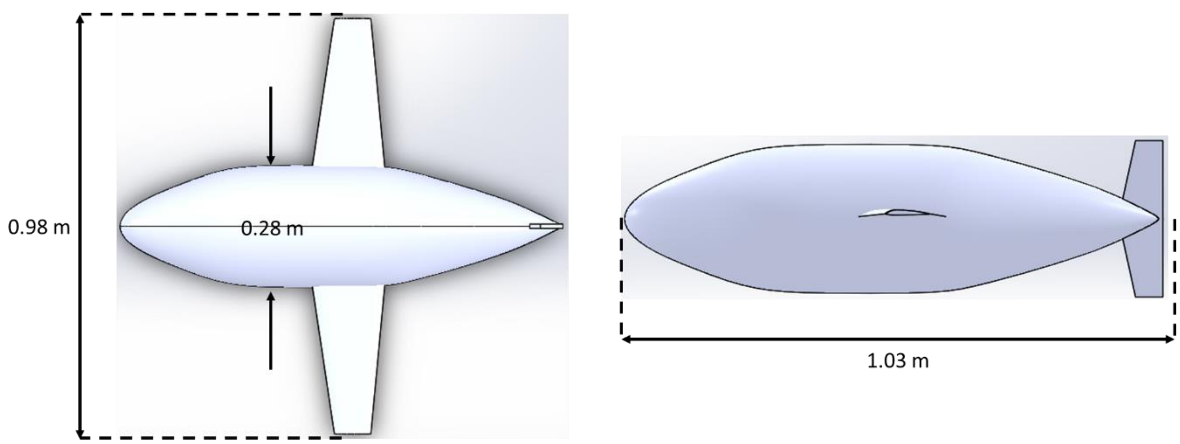


Figure 3.2: UTP’s glider model.

Figure 3.3 (a) (b) shows the top view and side view of the glider model with dimension. The length of the glider is 1.03 m, the diameter is 0.28 m and the wingspan is 0.98 m



(a) (b)

Figure 3.3: (a) Top view of UTP’s glider model. (b) Side view of UTP’s glider model.

3.2.2 Glider Formation

The glider formation modelling was done using Solid Works. The project was focused on "V" formation and the alternative formation which will be called 3D "V" formation which can be seen in Figure 3.4 and Figure 3.5 respectively. The transverse length, T, longitudinal, L, and vertical length, V is manipulated to determine the effect of glider separation to the drag. As seen in Figure 3.4, "V" formation does not have vertical length separation, it is only projected in one plane.

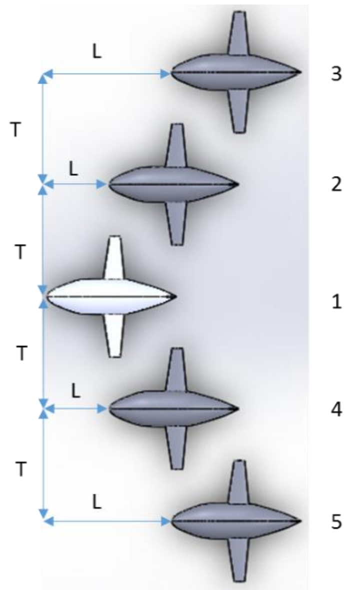
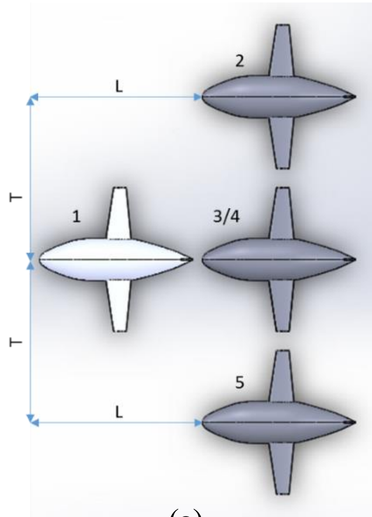
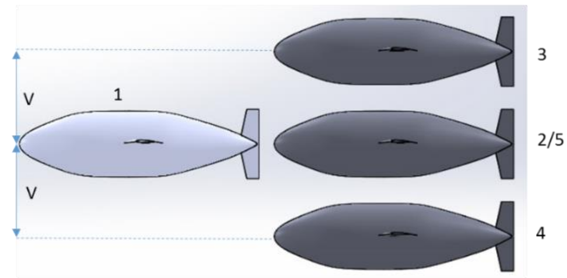


Figure 3.4: Top view of "V" formation.

Figure 3.4 (a) shows the top view of 3D "V" formation while (b) shows the side view. 3D "V" formation is an alternative formation configured to accommodate the same number of glider in a "V" formation with smaller foot print area. In this formation, the V shape of the formation can be seen from both top and side view.



(a)

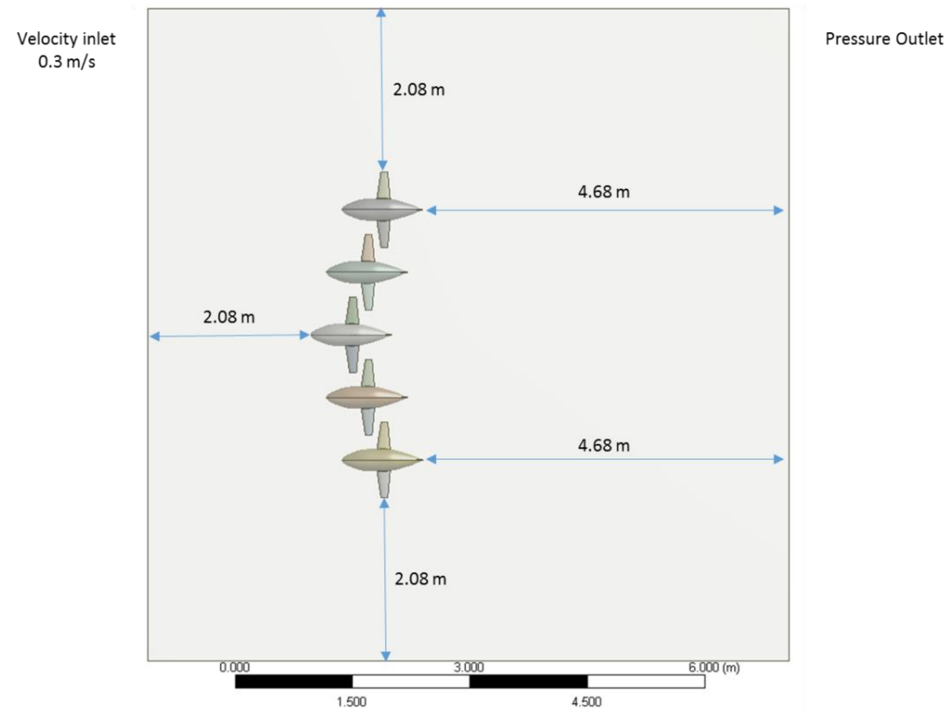


(b)

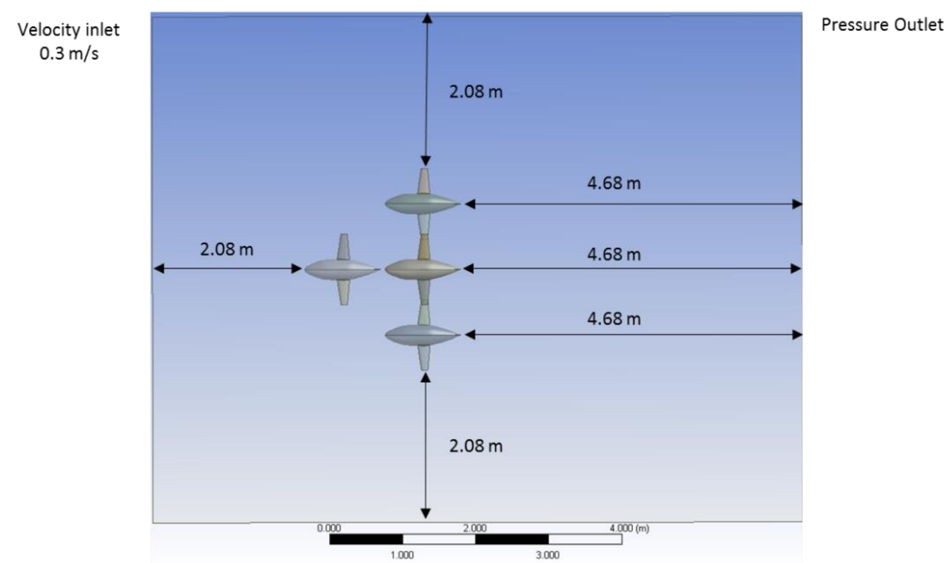
Figure 3.5: (a) Top view of 3D “V” formation (b) Side view of 3D “V” formation.

3.2.3 Fluid Domain Modelling

The fluid domain should be larger than the size of the glider fleet model to ensure that it does not affect the analysis [12]. The fluid domain in this study will be in the shape of a box and varies for each glider configuration, but the distance of the leading gliders from the velocity inlet is 2.08 m, distance of trailing gliders from the pressure outlet is 4.68 m and the distance of the outer glider to the side walls will be 2.08 m as can be seen in Figure 3.6 (a) (b).



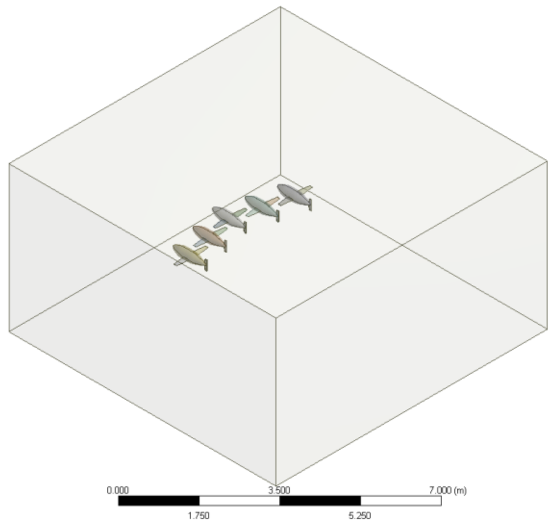
(a)



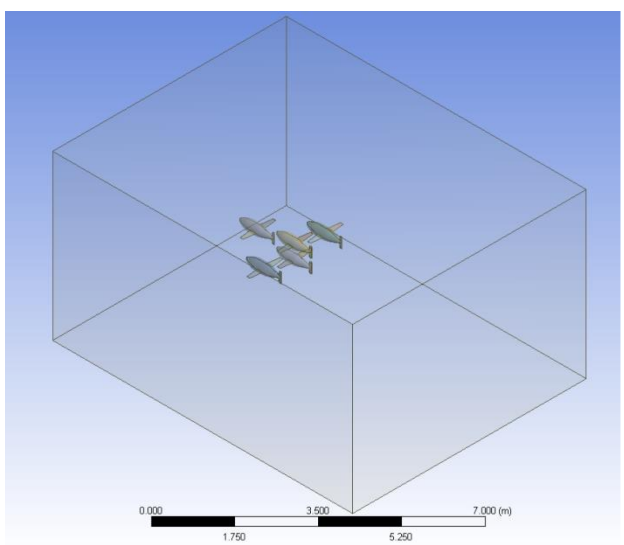
(b)

Figure 3.6: (a) Distance of glider within the fluid domain in "V" formation. (b) Distance of glider within the fluid domain in 3D "V" formation.

The position of the glider in the fluid domain can be seen in Figure 3.7 (a) (b). The size of the fluid domain differs. The "V" formation fluid domain is larger compare to the 3D "V" formation. This is because the 3D "V" formation requires lesser foot print area as compared to "V" formation.



(a)



(b)

Figure 3.7: (a) "V" formation glider in fluid domain. (b) 3D "V" formation glider in fluid domain.

3.2.4 Glider and Fluid Domain Meshing

Selection of mesh size affects the accuracy and complexity of the analysis. Medium mesh was for this project. The elements size for the gliders mesh is 0.07m. Medium size mesh is used instead of fine mesh due to the limitation of the ANSYS license available, maximum of 521000 elements allowed. To ease the meshing process, unstructured mesh was used. Figure 3.8 shows the fluid domain meshing.

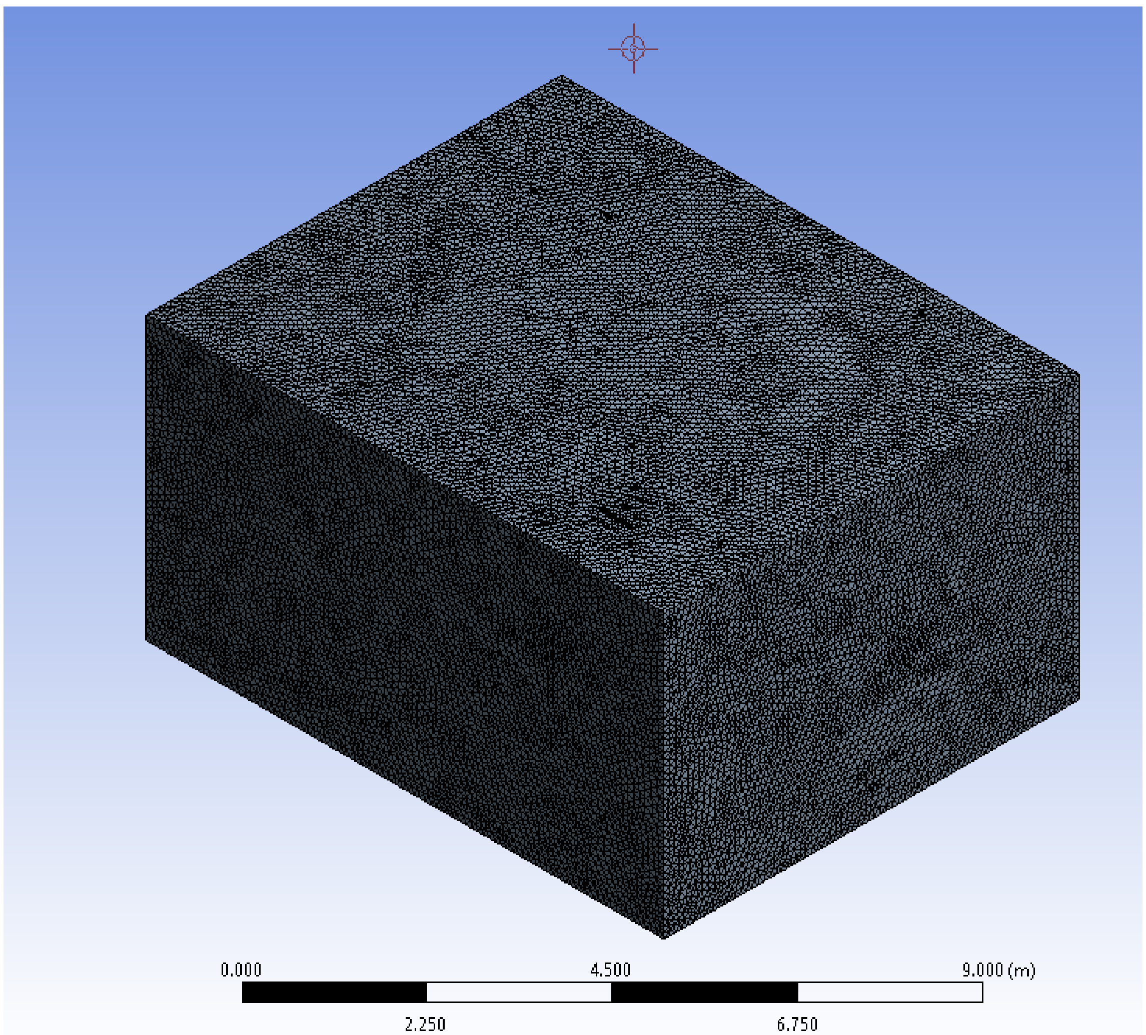


Figure 3.8: Fluid domain meshing.

3.2.4 ANSYS Fluent Simulation

The simulation can be done in two ways, first, to set the flow field as static and the AUG's to move. Second, to set the AUG's as static and the flow field move at assigned velocity [12]. In this project the second option was used, where by the glider will be in static position and the flow field moved. The angle of attack of the glider was set as zero to represent motion in the horizontal axis only. Re-Normalization Group (RNG) k-epsilon model with non-equilibrium wall function was used as the turbulence model for the project. The velocity was set at 0.3 m/s, average speed of a glider.

The simulation was initially done using "V" glider formation. The result obtained was used to verify the simulation model based on Rattanasiri work. Once verification was completed the simulation was run using the 3D "V" glider formation. The drag result obtained by each formation was recorded and graph was used to represent the result.

3.3 Gantt Chart

Content	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Project title selection: EFFECT OF TRANSVERSE, LONGITUDINAL AND VERTICAL SEPARATION ON DRAG FOR A FLEET OF AUTONOMOUS UNDERWATER GLIDER		■																										
Topic Introduction																												
Background study			■																									
Problem Statement			■																									
Objective			■																									
Scope of Study			■																									
Reviewing of topic introduction				■																								
Literature Review																												
Type of AUG				■	■																							
Current use of AUG				■	■																							
AUG Fleet configuration				■	■																							
Methodology																												
Glider formation modelling						■	●																					
Modelling of flow field and meshing								■	■	■																		
Simulation Parameter and Boundary Condition Set up											■	■	■	■														
Project																												
Confirmation of study parameter and boundary conditions														■	■													
Preliminary simulation with "V" formation															■	■	■											
Preliminary simulation data validation																	■	■●										
Final simulation with 3D "V" formation																			■	■	■●							
Final simulation data (Drag) analysis																					■	■	■					
Completion of project report																								■	■	■●		

● Milestone

CHAPTER 4

RESULTS AND DISCUSSION

4.1 "V" Formation Drag Result

From Figure 4.1, can be seen that the lowest drag occurs at longitudinal separation of 0.8 m for 0.7 and 0.8 m transverse separation with 2.24 N and 2.25 N respectively.

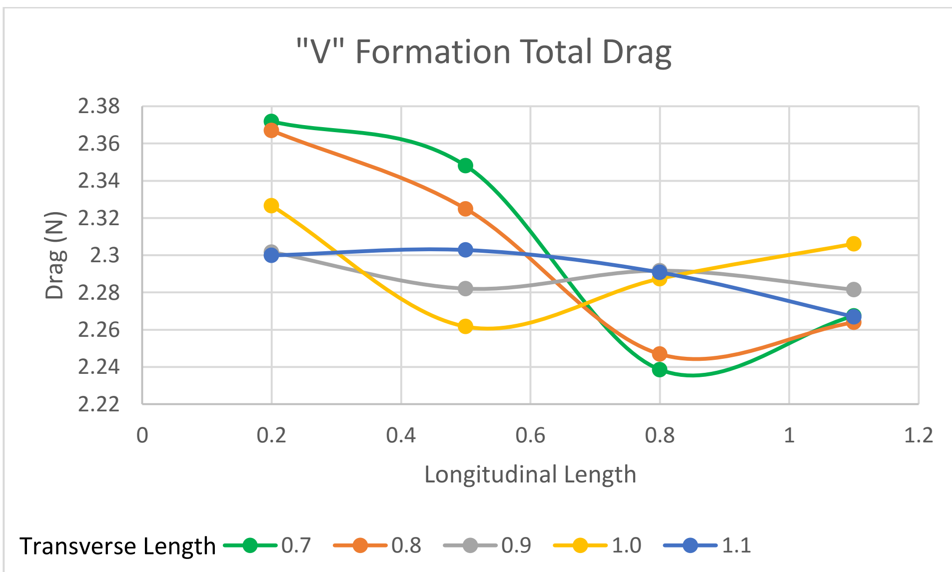


Figure 4.1: "V" Formation Total Drag.

Based on Figure 4.2 and Figure 4.3, it can be seen that the pressure drag contributed to the total drag of the glider fleet while the skin friction drag has a minor effect on the total drag.

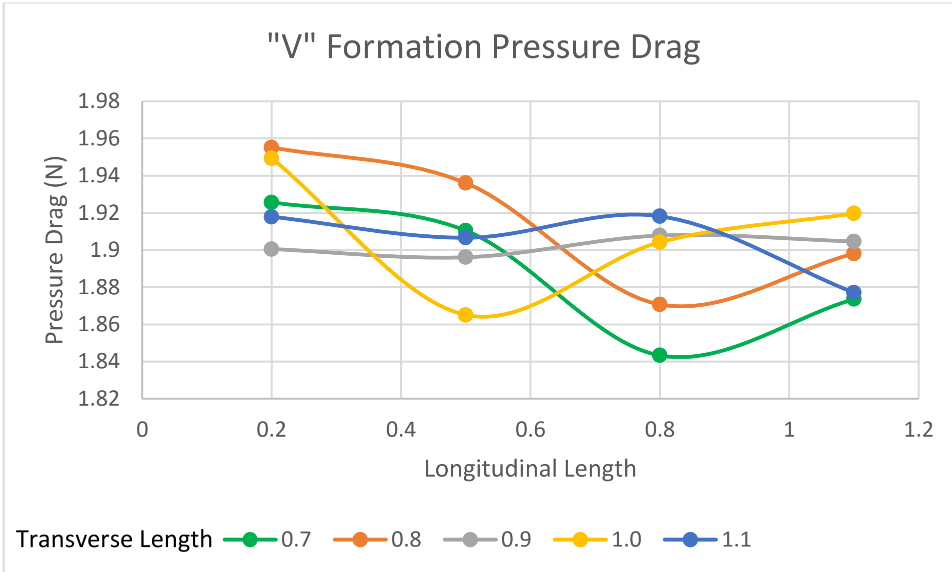


Figure 4.2: “V” Formation Pressure Drag

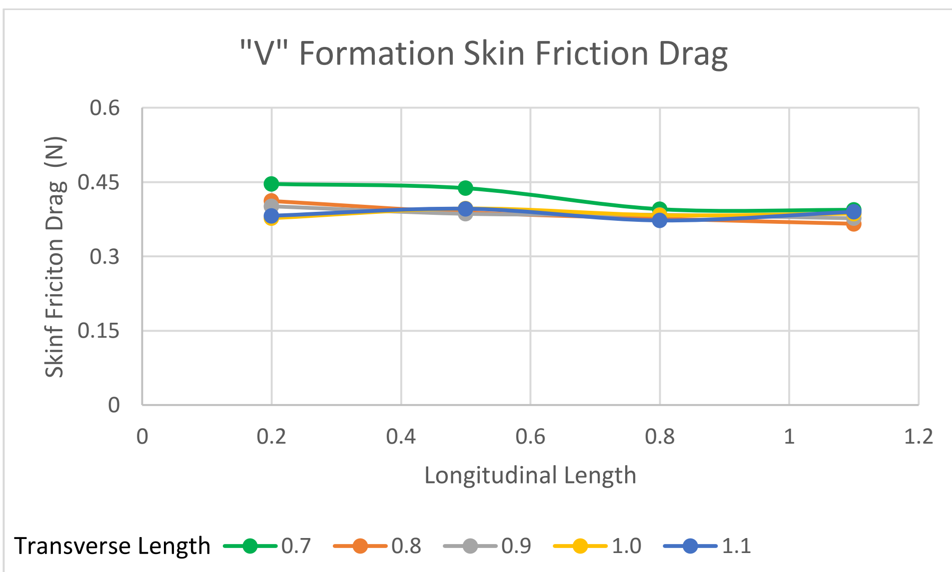


Figure 4.3: “V” Formation Skin Friction Drag

4.2 3D “V” Formation Drag Result

Figure 4.4 shows the total drag result of the 3D “V” formation, based on the graph it can be seen that the lowest drag of 2.27 N for 3D “V” formation is achieved at 1.1 m of longitudinal and transverse separation with 0.2 m vertical separation.

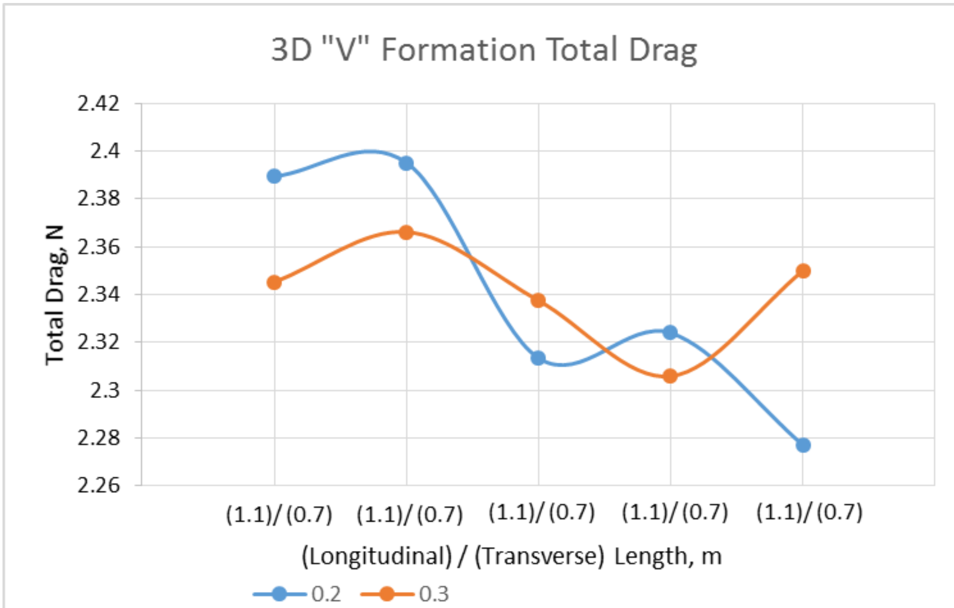


Figure 4.4: 3D “V” Formation Total Drag.

Based on Figure 4.5 and Figure 4.6, it can be seen that the pressure drag contributed to the total drag of the glider fleet while the skin friction drag has a minor effect on the total drag similar to the drag result of the “V” formation.

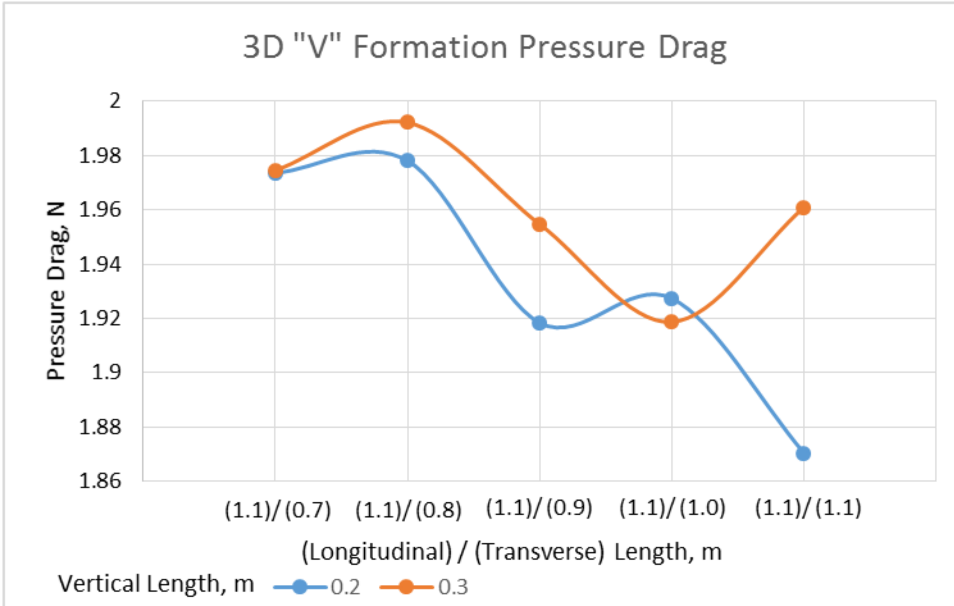


Figure 4.5: 3D "V" Formation Pressure Drag.

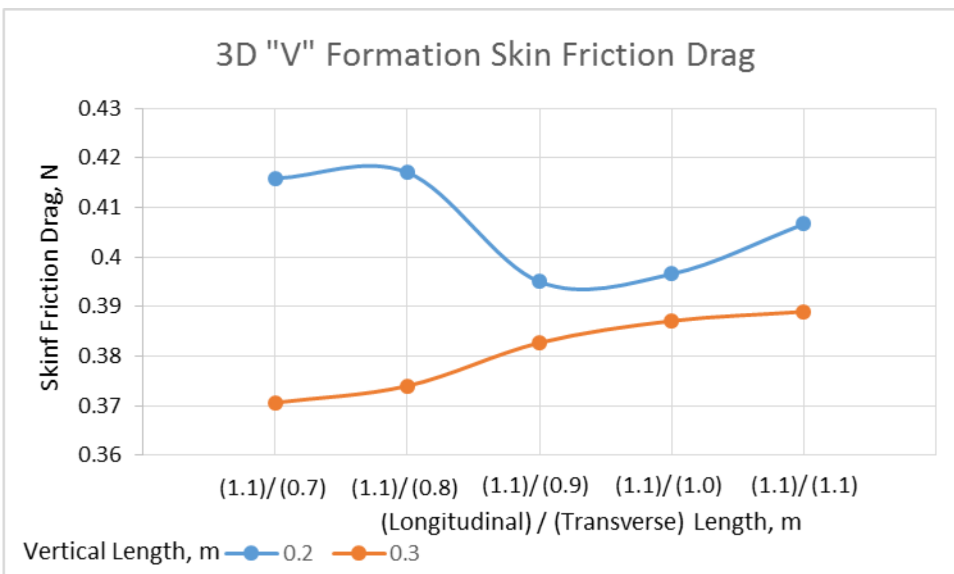


Figure 4.6: 3D "V" Formation Skin Friction Drag.

4.3 Discussion

Simulation for “V” formation was done to validate the simulation model. As shown by Rattanasiri the drag of the glider fleet decreases as the longitudinal length increase before increasing back [8]. This trend can be seen for 0.7 m, 0.8 m and 1.0 m transverse separation in Figure 4.1.

3D “V” formation was developed to reduce the foot print area required as compared to the normal “V” formation. Even though the reduction of foot print area is achieved, it will be redundant if the drag are high. Thus, simulation was conducted for various transverse, longitudinal and vertical length. The lowest drag obtained for 3D “V”, 2.27 N is relatively close to the lowest drag of the “V” formation which ranges from 2.24-2.28 N. This shows that we can achieve a low drag with a much compact formation.

“V” pattern have been proven to be beneficial to the trailing birds in the formation due to the vortices and uplift by the leading birds [9]. 3D “V” formation shows “V” pattern when it is seen from both top and side view. This could have contributed to the low drag obtained by the formation.

Based on the results obtained for the 3D “V” formation in Figure 4.5, the pressure drag is higher when the vertical separation is 0.3 m and lower when it is 0.2 m. The pressure drag generally decrease as the transverse length increase for both 0.2 m and 0.3 m vertical separation. This could have been caused by the vortices and uplift generated by the leading glider.

Based on Figure 4.6, skin friction drag is higher when the separation is 0.2 m and lower when the distance increases to 0.3 m. The skin friction drag generally decrease with the increase in transverse length for vertical separation of 0.2 m while the skin friction drag increases with increase in transverse length for vertical separation of 0.3 m. This shows that skin friction drag is affected by the flow of the fluid around the glider body.

The pressure drag are much higher compare to the skin friction drag as seen from Figure 4.5 and Figure 4.6 respectively, because the pressure drag is affected directly by the shape of a body. The complex shape of the glider contributed to the pressure drag.

CHAPTER 5

CONCLUSION

The aim of the project was to determine an alternative “V” formation which requires less foot print area. A 3D “V” formation was configured to achieve this objective. Figure 5.1 shows the configuration of the proposed 3D “V” formation.

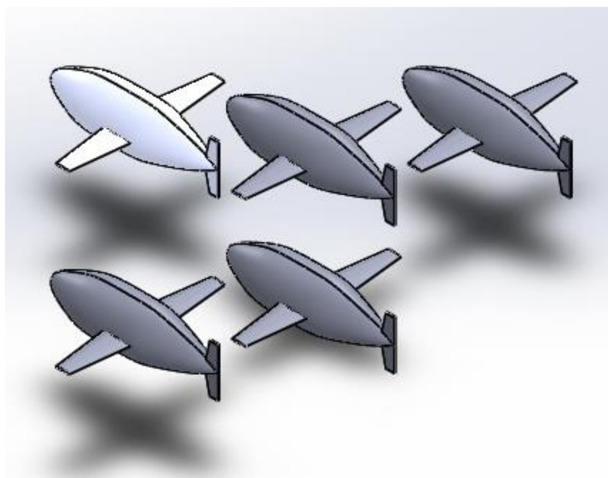


Figure 5.1: 3D “V” glider formation.

Based on the simulation result shown in Figure 4.5 and Figure 4.6 we can observe that the pressure drag is higher when the vertical separation is longer and the skin frication drag is higher when the vertical separation is shorter. Further simulation which includes more transverse, longitudinal and vertical separation could be conducted in order to study in depth correlation between transverse, longitudinal and vertical separation.

3D “V” formation drag results in Figure 4.4 shows that a low drag of 2.7 N can also be achieved with a much compact formation. Lowest drag was achieved at 1.1 m of longitudinal and transverse separation with 0.2 m vertical separation. This shows that low drag can also be achieved with compact formation that requires less foot print area.

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APPENDIX

APPENDIX 1: Type of Autonomous Underwater Glider

Attribute	Slocum	Spray	Seaglider
Hull (and Fairing)	1.5 m length, 21.3 cm diameter	2 m length, 20 cm diameter	1.8 m length, 30 cm diameter
Mass	52 kg	51 kg	52 kg
Batteries	260 Alkaline C cells, 8MJ	52 Lithium CSC DD cells, 13 MJ	81 Lithium D cells, 10 MJ
Volume Change	520 cc, 90 W single-stroke pump, 50% efficiency	900 cc, Motor & reciprocating pump, 20 % - 50% efficiency	840cc, Motor & reciprocating pump, 8% - 40% efficiency
Speed	0.4 m/s	0.45 m/s	0.45 m/s
Max Depth	200 m	1500 m	1000 m
Wings	98 cm Span, 14 cm chord (MAC), 45° sweep	120 cm span 10 cm chord (MAC)	100 cm span, 16 cm chord (MAC)

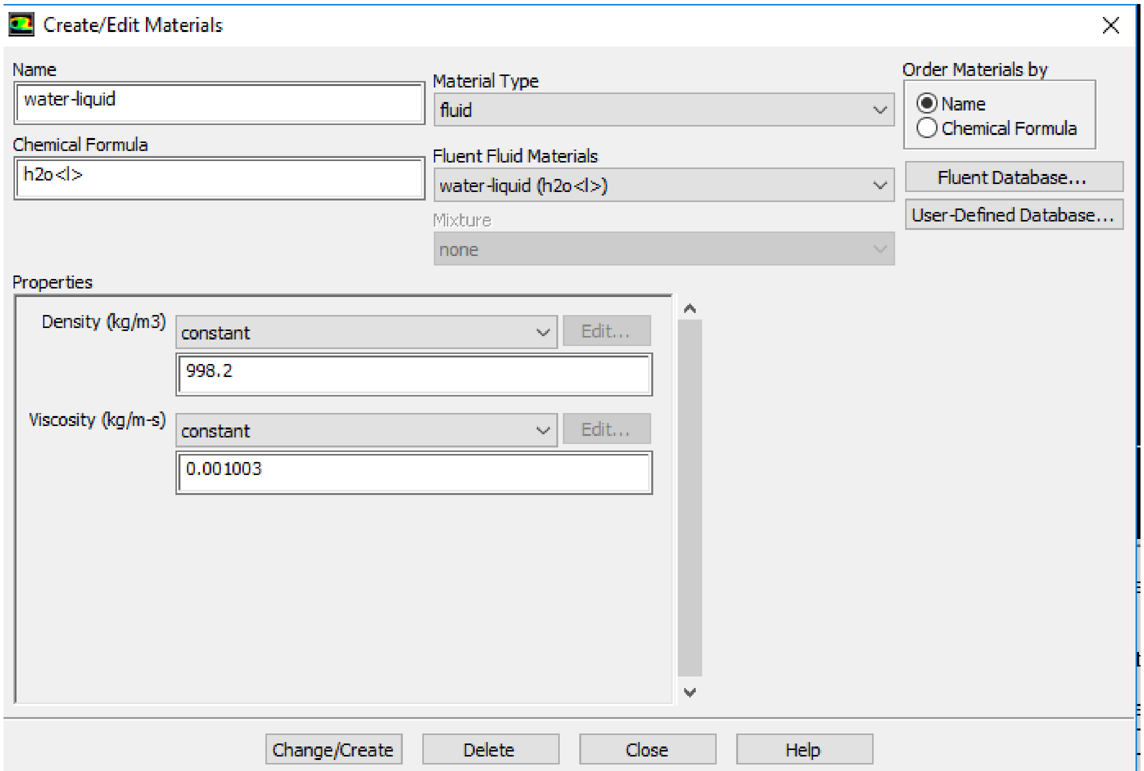
APPENDIX 2: Mesh Sizing

Sizing	
Use Advanced Size Fun...	On: Proximity and Curvature
Relevance Center	Medium
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Medium
Curvature Normal A...	Default (45.0 °)
Num Cells Across Gap	Default (3)
Min Size	0.10 m
Proximity Min Size	Default (3.1575e-003 m)
Max Face Size	0.10 m
Max Size	0.30 m
Growth Rate	Default (1.850)
Minimum Edge Length	1.3441e-003 m

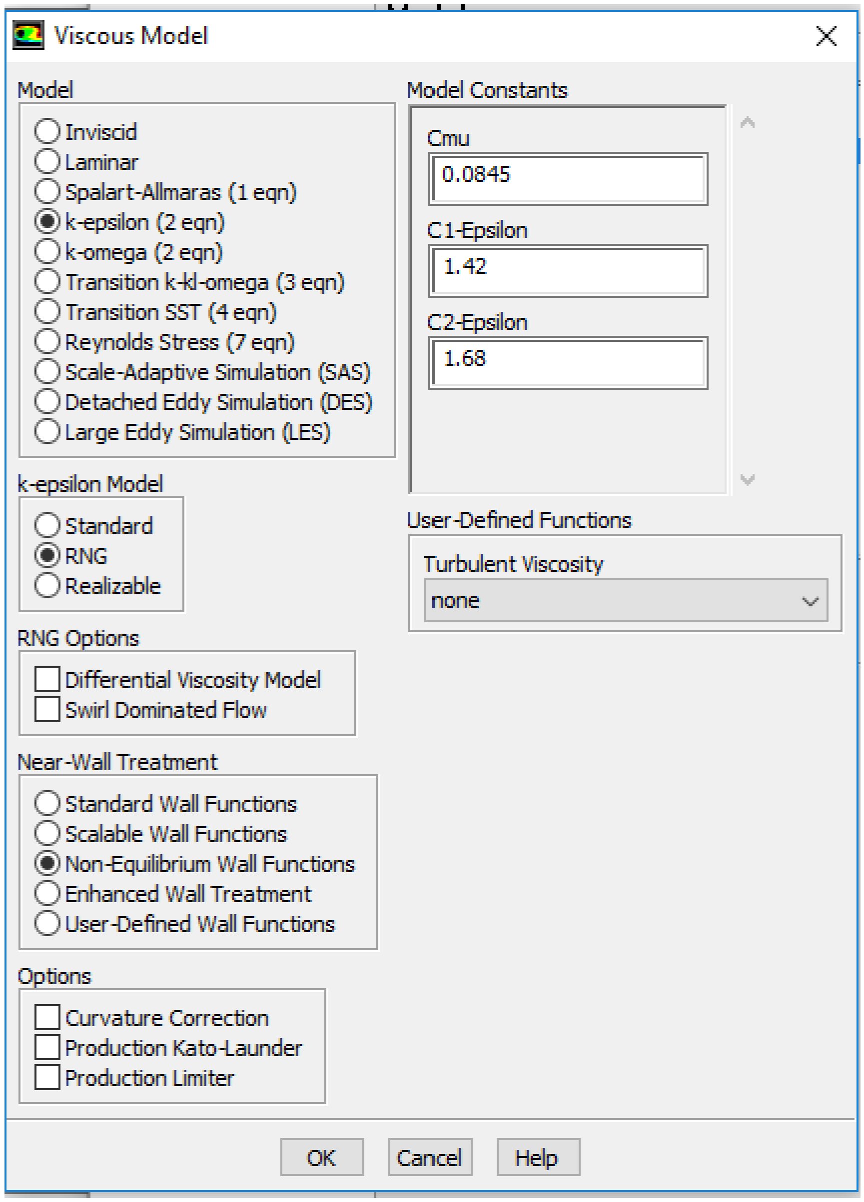
APPENDIX 3: Glider Face Size

Object Name	*Face Sizing*
State	Fully Defined
Scope	
Scoping Method	Named Selection
Named Selection	Glider
Definition	
Suppressed	No
Type	Element Size
Element Size	7.e-002 m
Behavior	Soft
Curvature Normal Angle	Default
Growth Rate	Default
Local Min Size	Default (3.1575e-003 m)

APPENDIX 4: Fluid Domain Material



APPENDIX 5: Turbulence Model



APPENDIX 6: Convergence History