The Study of Hydroplane for Submarine Hull Form Using Experimental Method and CFD Study

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SUMMARY

In designing submarines, hull form selection, resistance, and powering are key aspects and also hydroplanes as horizontal control surfaces are used to control the vertical motions of submarines and other underwater vehicles. The shape, area and location of hydroplanes will depend on the size, speed and operational requirements of the submarine. Hydroplanes must therefore be able to apply upward or downward force to submarine and provide a pitching moment. Two pairs of control surfaces are required, being normally situated near the fore and aft ends to provide the largest moments. In this study one pair of hydroplane is installed near the aft ends. CFD simulations enable surface condition analysis using FINEMarine. The results show that the lifting force for the AOA is 25 degrees and 1.4 m/s. Furthermore, in this condition, the pitch motion is close to zero degrees.

NOMENCLATURE

AoA	Angle of Attack (degree)
D_H	Hull Diameter (m)
L_B	Bow length (m)
L_C	Cylinder length (m)
L_{CS}	Conical Stern length (m)
LOA	Length overall (m)
LWL	Length waterline (m)
R_t	Total resistance (N)
T	Draught (m)
V	Speed of vessel (m/s)
Δ	Displacement (tonnes)
γ	Conical Stern angle (degree)

1. INTRODUCTION

Hull form selection, resistance, powering and also hydroplanes are important in designing submarines. CFD simulation was carried out to control the pitch motion in near-surface conditions. The model had hydroplanes installed near the aft ends. Hydroplanes are horizontal control surfaces used to control the vertical motions of submarines and other underwater vehicles.

CFD tools are widely used for the prediction of ship resistance and powering with appendages. As such, CFD codes were also used for the pitch motion control. The model experiments were carried out to measure resistance and downforce in the Ship Model Towing Tank (SMTT) at Marine Hydrodynamics Centre, Myanmar Maritime University 3. The SMTT is 60m in length, 4m in breadth, and 4m in depth, with a water level of 3m. The maximum carriage speed of the SMTT is 4 m/s.

2. OBJECTIVE

This paper analyses the performance of hydroplanes for submarine hull form by CFD simulation.

3. STUDY AREA

Despite being primarily designed for optimal performance when submerged, submarines must also be able to operate well on the water surface. Modern submarine hulls are inefficient when operating on the surface, resulting in poor resistance performance. Submarines have a low freeboard compared to normal ship surfaces, meaning the majority of the hull sits below the water surface. As such, when operating at relatively high Froude Numbers, wave making resistance becomes dominant. Hydroplanes are key aspects to control the vertical motions of submarines.

The shape, area and location of hydroplanes will depend on the size, speed and operational requirements of the submarine. Hydroplanes must therefore be able to apply upward or downward force to the submarine and provide a pitching moment. Two pairs of control surfaces are required, being normally situated near the fore and aft ends to provide the largest moments. In this study one pair of hydroplane is installed near the aft ends.

Initially, a 1.5m long wooden model was manufactured and tested in the model basin of the Myanmar Maritime University for resistance and downward force measurement. A CFD simulation was carried out to control the vessel's pitch motion.

The CFD solver is capable of calculations with multi-phase flows and moving grids. In the multi-phase continuum, considering the incompressible flow of viscous fluid under isothermal conditions, the mass, momentum, and volume fraction conservation equations can be written as (FINE™ / Marine 9.1, Theory Guide) –

$$\frac{\partial}{\partial t}\int_V p dV + \int_S p(\vec{U} - \overrightarrow{U_d})\vec{n} dS = 0 \quad (1)$$

where V is the domain of interest, or control volume, bounded by the closed surface S, with a unit normal vector $\vec{n}$ directed outward. $\vec{U}$ and p represent the velocity and pressure fields, respectively.

When the grid is moving, the so-called "space conservation law" must also be satisfied:

$$\frac{\partial}{\partial t}\int_V dV = \int_S \overrightarrow{U_d}\ \vec{n} dS = 0 \quad (2)$$

4. STUDY APPROACH

4.1 Determining the main dimensions

The propeller-hull interaction results in the submarine bare hull form being based on the following five parameters (Burcher & Rydill, 1995):

- The fineness ratio
- Prismatic coefficient
- Nose radius
- Tail angle and
- The position of the maximum section.

The dimensions of a submarine model with the parallel middle body form are described in table 1. L/D relation is 8.3. The vessel design consists of an elliptical main hull, a conical stern and hydroplanes profiled NACA0012 (Figure 1).

Table 1: Main particulars of model at design condition.

Main particulars		Unit
Overall length, LOA (m)		1.500
Hull vertical diameter, D_{VH} (m)		0.210
Hull horizontal diameter, D_{HH} (m)		0.180
Displacement, Δ (tonnes)		0.028
Bow length, L_B (m)		0.333
Cylinder length, L_C (m)		0.590
Conical stern length, L_{CS} (m)		0.576
Draught, T (m)		0.170
Conical stern angle, γ (degree)		20.20
Hydroplane (NACA0012 profile)		
	Chord length (m)	0.13619
	Span length (m)	0.055

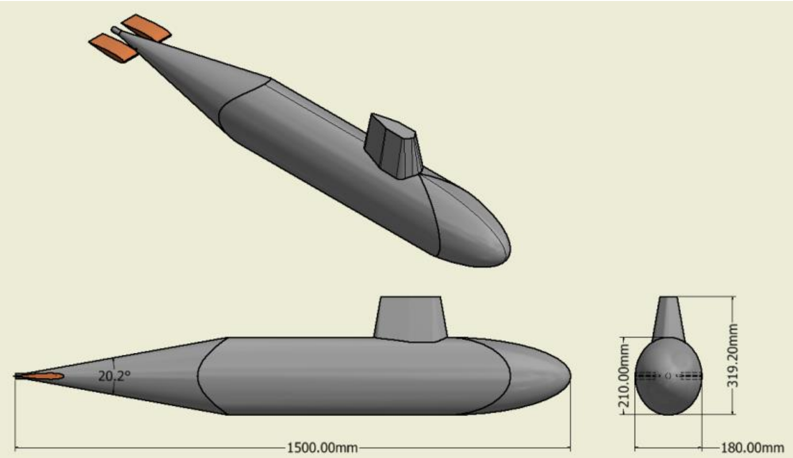


Figure 1: Model of submarine with hydroplanes.

4.2 Hydrodynamic effect of the model

The model without appendages was tested in the towing tank on the surface condition, with the observation being made that even keel conditions could not be controlled (Tun & Htun, 2021). The CFD simulation was also carried out for even keel using FINEMarine. The pressure distribution on the hull is shown in Figure 2. As a result, the hydroplanes was designed to control the pitching motion of the model (Figure 3). The hydroplanes NACA0012 profile are detailed in Table 2.

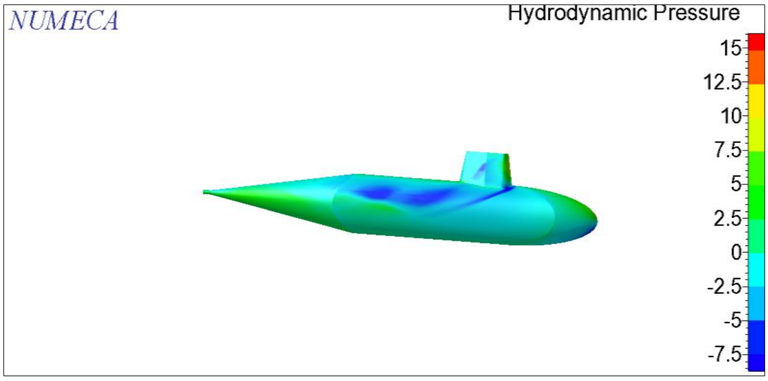


Figure 2: Hydrodynamic effect of the model.

Table 2: Coordinates of NACA 0012 airfoil section in mm.

X	Y	Z
0	0	0
1.268596	2.243131	0
5.027141	4.243122	0
11.13556	5.915699	0
19.36629	7.167012	0
29.41263	7.926912	0
40.90027	8.173742	0
53.40117	7.941852	0
66.44957	7.311578	0
79.55928	6.389	0
92.24183	5.285656	0
104.0247	4.106333	0
114.4688	2.94643	0
123.185	1.894989	0
129.8486	1.036515	0
134.2113	0.446758	0
136.19	0.171599	0

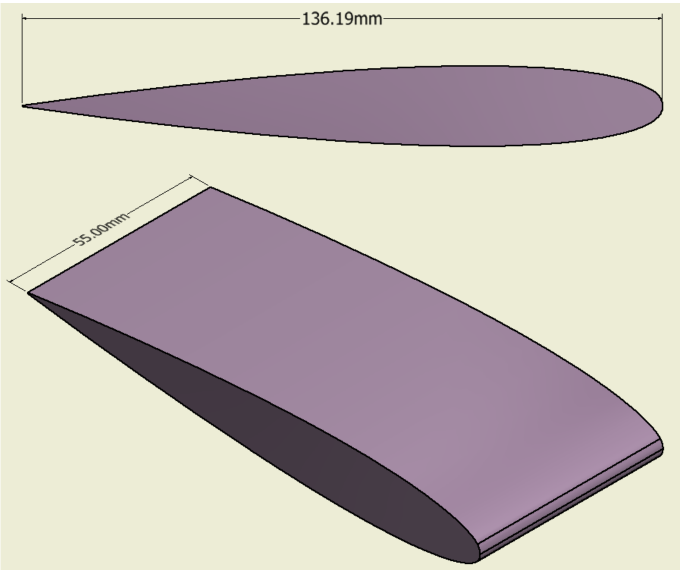


Figure 3: Hydroplane NACA0012 profile section and 3D model.

4.3 Experimental approach

The towing tests were conducted over a 0.6 to 1.8 m/s speed range (Table 3). The test conditions were: zero trim, 0.170m of draught, and the towing tank water level was 3m (Tun, Htun and Min, 2021).

Table 3: Model resistance test.

Speed of vessel V (m/s)	Total resistance of model R_t(N)	Downforce (N)
0.6	0.800	0.720
0.8	2.187	2.764
1.0	4.522	6.129
1.2	7.937	10.796
1.4	7.457	10.446
1.6	12.497	8.794
1.8	18.015	7.363

4.4 Numerical approach

Numerical methods have strongly advanced in this field, meaning a combined use of both model tests and CFD codes can be very effective in aiding ship design and for understanding ship hydrodynamics (Watson, 1998). Firstly, CFD simulation was performed to inverstigate the lift force of hydroplane in order to cover downforce. The flow setting is 1.6 m/s with the AoA 25 degrees.

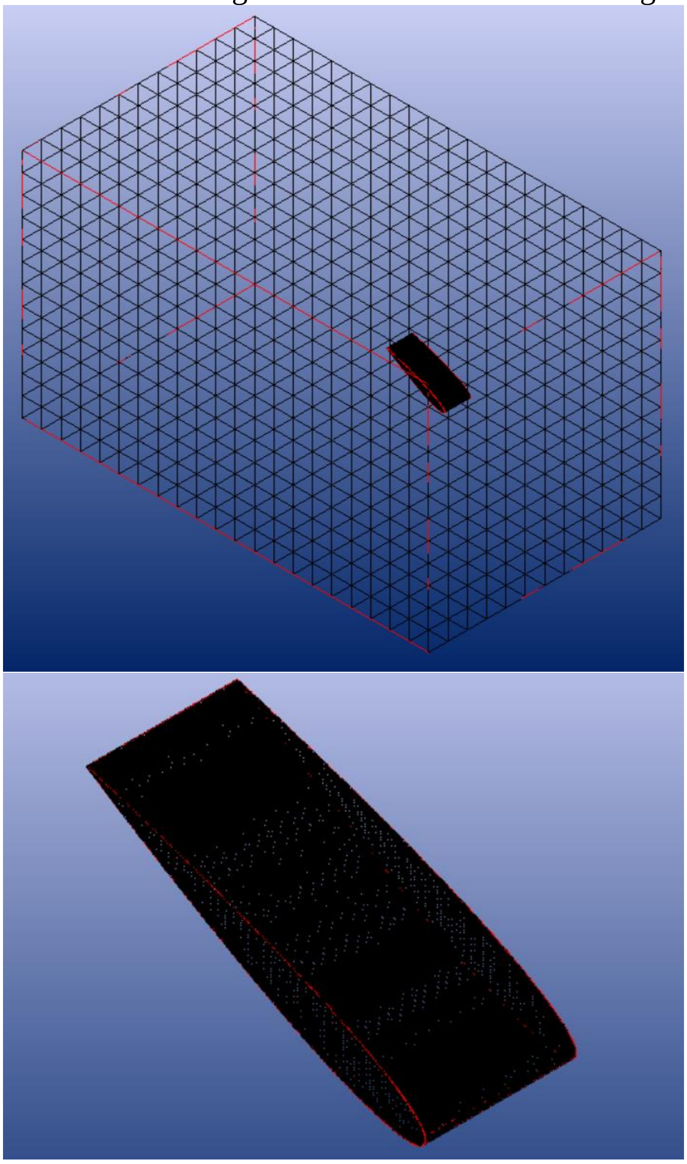
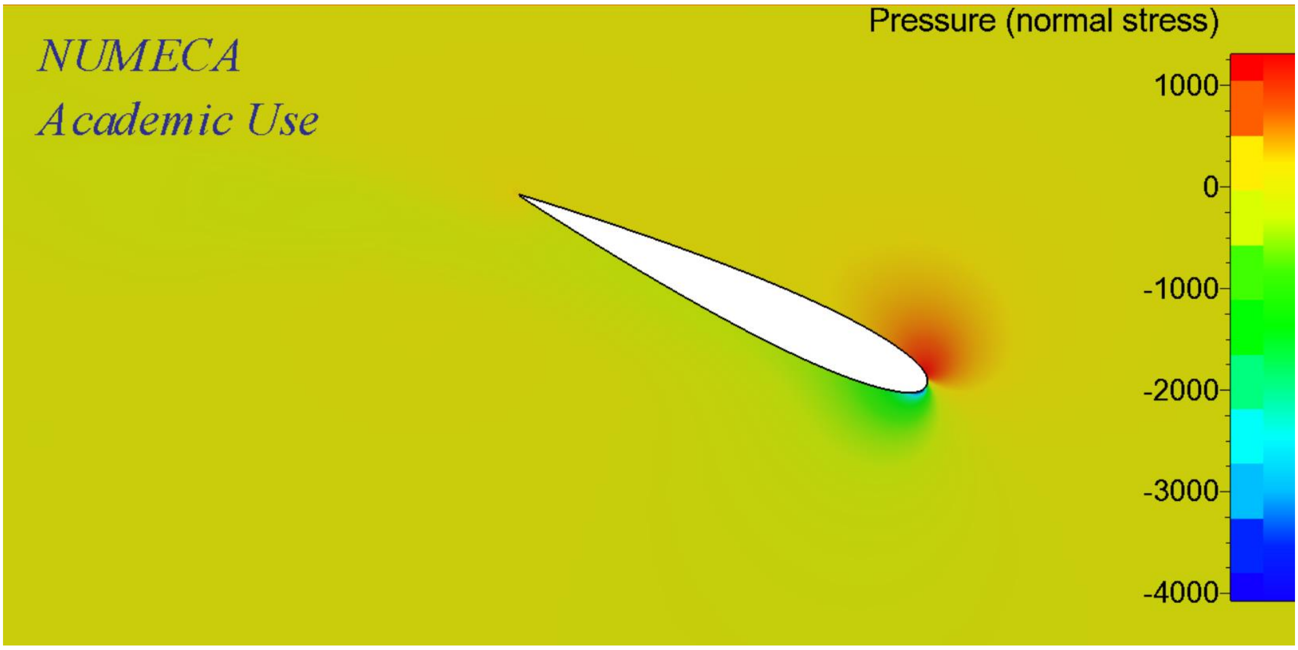
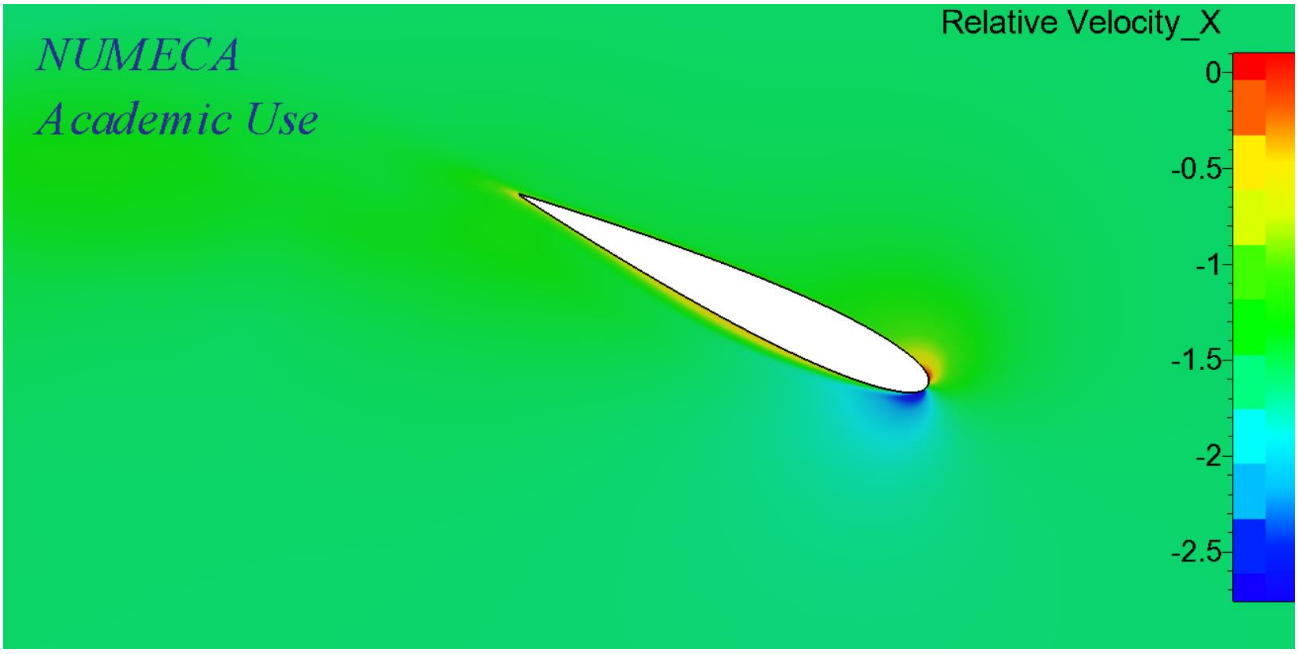


Figure 5: Generated mesh of the hydroplane(NACA0012).

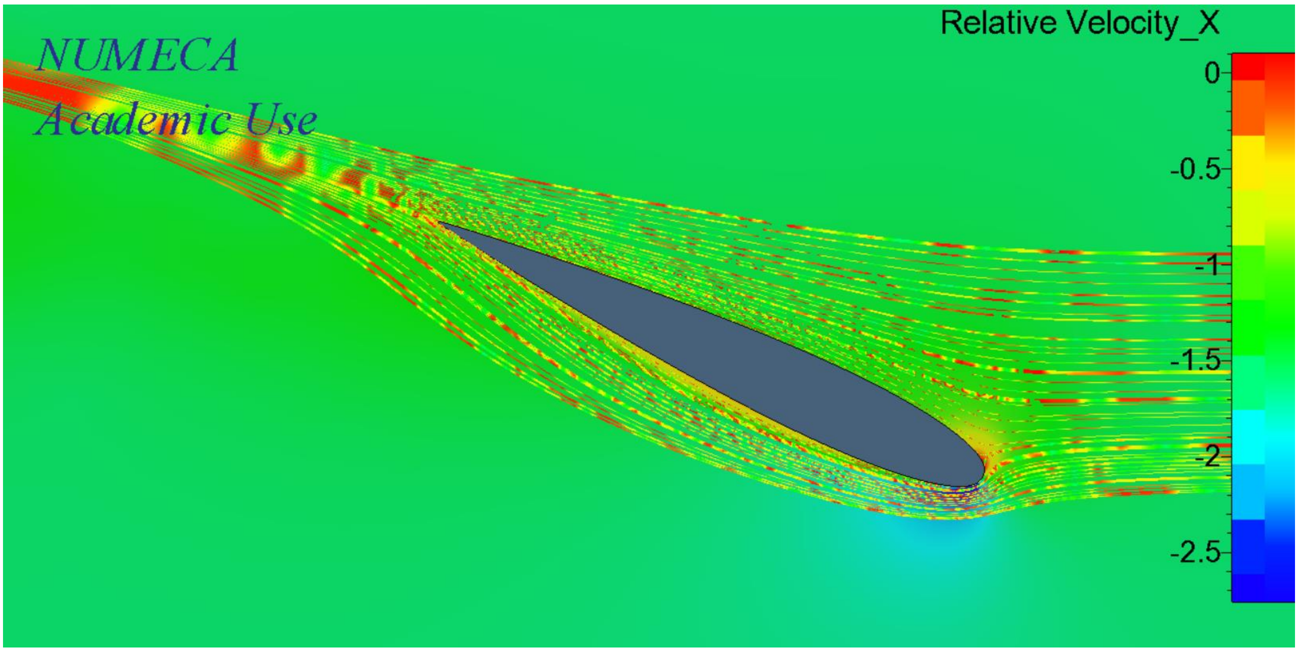
The CFD simulation tested a speed of 1.6 m/s. A result of hydroplane at 1.6m/s speed and the AoA 25 degrees are shown in Figure 6 (a to c).



(a) Pressure distribution around the hydroplane.



(b) Velocity distribution around the hydroplane.

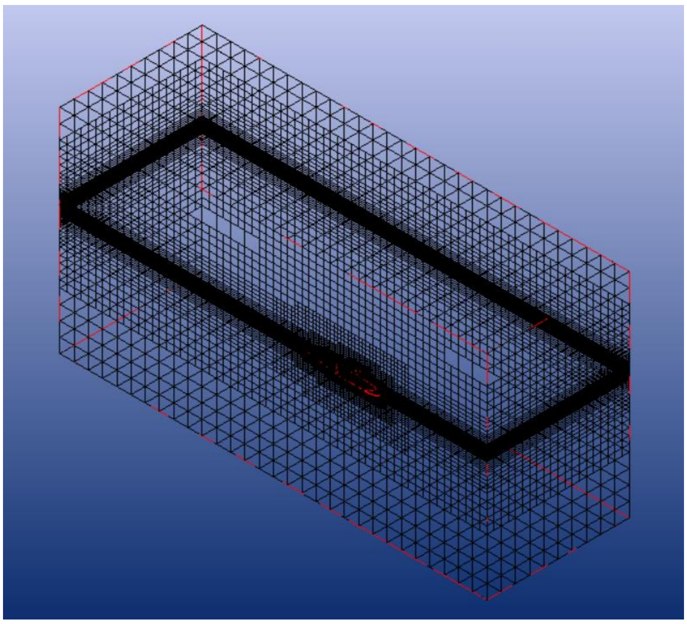


(c) Streamline around the hydroplane.

Figures 6a-6c: Result of hydroplane at 1.6m/s speed and the AoA 25 degrees.

The average downward and drag forces per hydroplane are 5.8N and 2.3N repectively. Therefore, the total downward and drag forces are 11.6N and 4.6N repectively. The designed shape, size and area of hydroplanes coverd the tested downforce 8.394N from Table 3.

After simulation of downward force, pair of hydroplanes are attached near the aft ends of submarine. And then, Numerical simulation was carried out for submarine with hydroplanes model to inverstigate the pitch motion. The initial mesh had an X axis of 30, a Y axis of 10, and a Z axis of 15, with the total cells being 1333732 (Figure 7). The minimum mesh width was 0.00135m. The computed first layer thickness/the distance of the nearest grid point to the wall (Y_{wall}) was 0.001839m. FINEMarine with the k-omega turbulence model (SST-menter) was used to perform numerical computations.



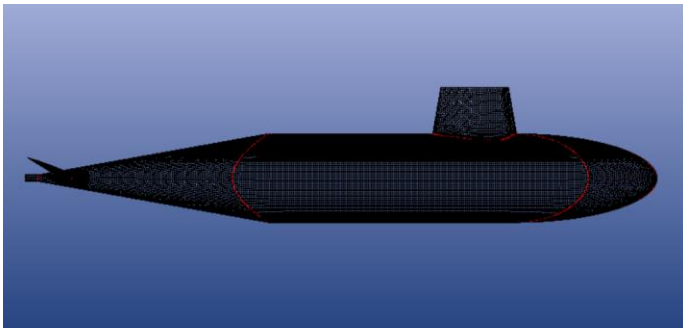


Figure 7: Generated mesh of the whole model.

The physical parameters were greater than the mesh parameters in terms of the boundary type of each surface. HEXPRESS™ took these conditions into account when computing a mesh in accordance with the future flow. For instance, a boundary layer mesh was computed to properly capture the flow next to the wall using a turbulence model. This highlights the importance of defining the boundary conditions during mesh setup. By default, each physical boundary is defined as a SOLID. Boundary conditions are listed in Table 4 (FINE™ / Marine 9.1, Theory Guide).

Table 4: Boundary conditions.

Description	Boundary condition type	
z_{min} (bottom of domain)	External	Prescribed pressure
z_{max} (top of domain)	External	
x_{min} (outlet of domain)	External	Far field
x_{max} (inlet of domain)	External	
y_{min} (- side of domain)	External	
y_{max} (+ side of domain)	External	
Model	Solid	Wall function

The domain size for this application is defined based on the Froude number (Fn) and the body reference length (length overall LOA of the model). The default numbers are shown in Figure 8.

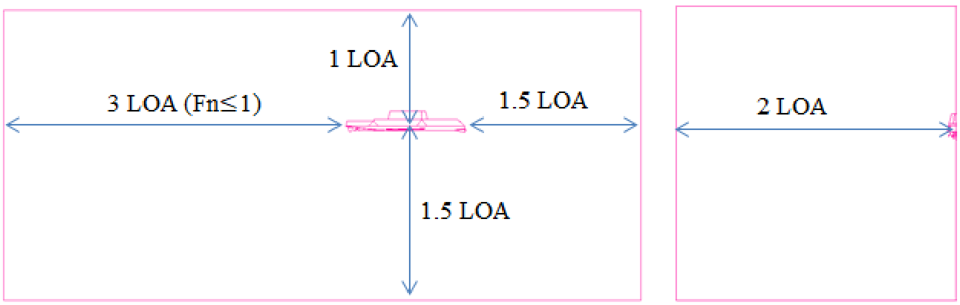


Figure 8: Computational domain size.

Wave elevation for submarine without hydroplanes (fixed trim) is shown in Figure 9. Wave elevation of submarine with hydroplane at 1.6m/s speed and the AoA 25 degrees is presented by Figure 10. It had been observed that hydrodynamic effect on the submarine was reduced due to hydroplanes (Figure 11).

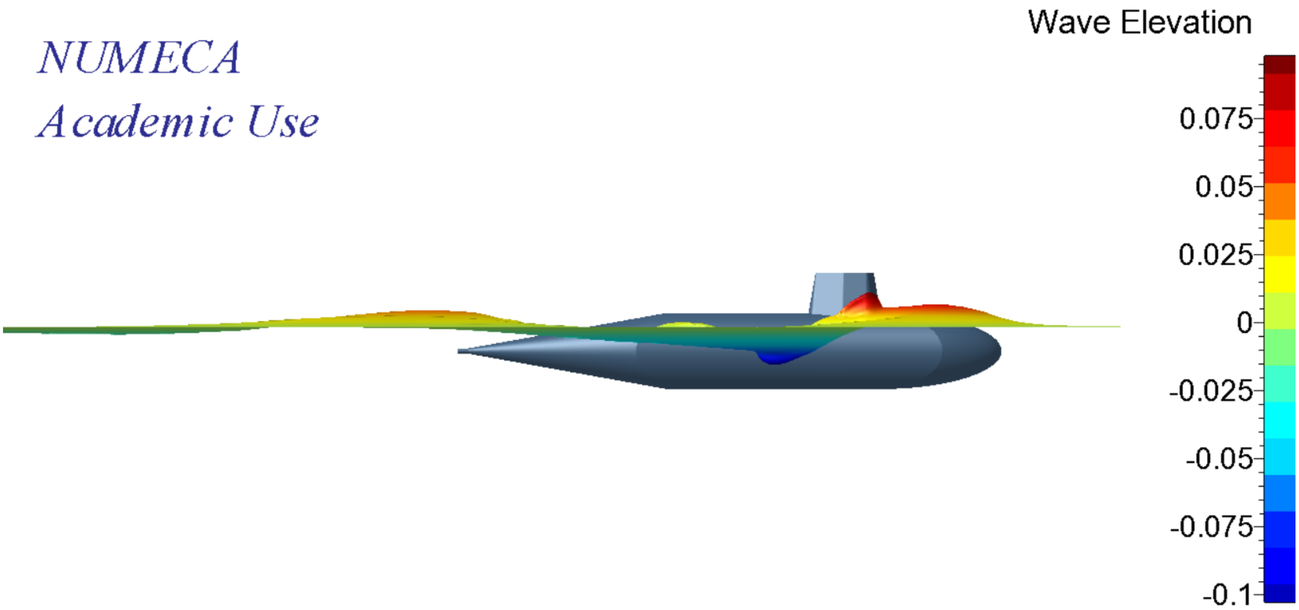


Figure 9: Wave elevation of submarine without hydroplanes (fixed trim)

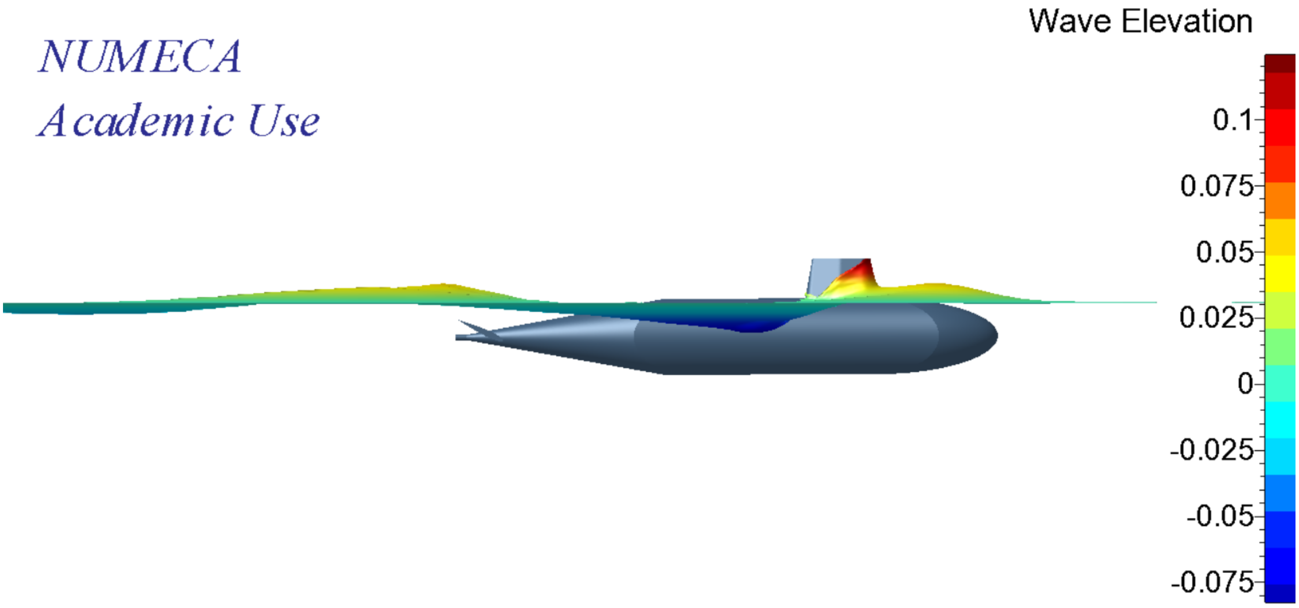


Figure 10: wave elevation of submarine with hydroplanes (free motion)

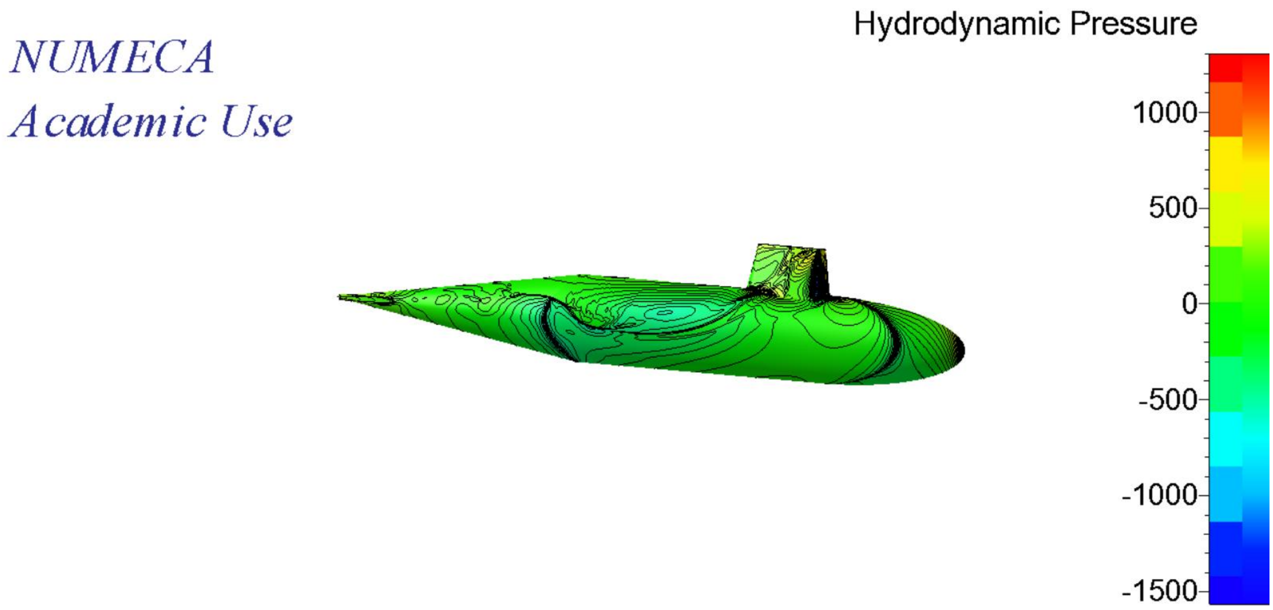


Figure 11: Hydrodynamic effect of submarine with hydroplanes (free motion and AoA 0 deg)

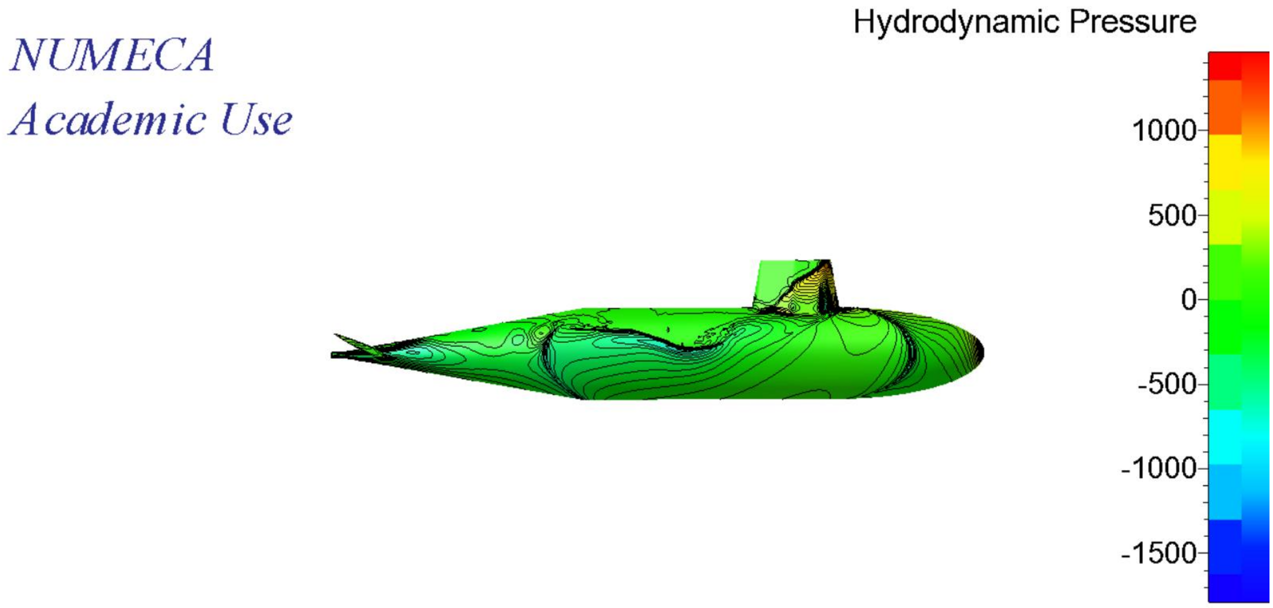


Figure 12: Hydrodynamic effect of submarine with hydroplanes (free motion and AoA 25 deg)

After testing CFD simulation for submarine with hydroplanes, the results are –

- The total resistance - 14.4N
- Heave - 0.033m
- Trim - 0.23 deg by stern

5. RESULTS DISCUSSION

Resistance increased about 15% from bare hull result at 1.6m/s and the AoA 25 degrees. At this condition, the bow wave near the bridge is high due to heave value 0.033m (Figure 10). The results (Figure 11 and 12) show that the hydrodynamic effect on the submarine decreases and the model's trim is nearly zero. Finally the result proved that hydroplanes are very important to ensure the pitch motion on the near surface or underwater conditions.

6. REFERENCES

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