Journal of Physics: Conference Series **776** (2016) 012087 doi:10.1088/1742-6596/776/1/012087

# Theoretical analysis of Sloshing effect on Pitch Angel to optimize quick dive on litoral submarine 22 M

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**Abstract**
This study considers the analytic theoretical model. The Submarine was considered to be rigid body are free sailing model with various angle of attack to be quick dive as pitching motion. By using Floating Body Mechanism supported by analytic model to describe the theoretical model analisys test. For the case of fluid level on 30% of the front balast tank and various angle of pitch. The paper describes a study on Analytic theoretical and modeling in CFD (Computational Fluid Dynamics). For Analyzing at special care of sloshing on free surce ballast tank after peak and fore peak were taken into consideration. In general, both methods (analytic model and CFD model) demonstrated such a good agreement, particularly in the consistent trend of RAO.

## 1. Introduction

The problem of water sloshing in closed forepeak ballast of . This phenomenon can be described as a free surface movement of the contained fluid due to sudden loads [1]. Sloshing is a liquid vibration phenomenon caused by the movement of the ballast. When the ballast is in transit, the sloshing would affect stability of the system severely caused by pitch of angle when submarine in quick dive cause couple motion [2]. So it is necessary to minimize the impact of sloshing and avoid large amplitude resonance. Sloshing has been studied for many years by analytical and numerical methods[3].

Originally the normal way of diving a submersible was by adjusting the amount of water ballast carried. Towards the end of the nineteenth century the most promising way was to get the boat to an 'awash' condition with a small amount of positive buoyancy and then drive it underwater. The main controversy was whether the boat should be dived horizontally or at an angle and this also applied to changing depth when submerged.

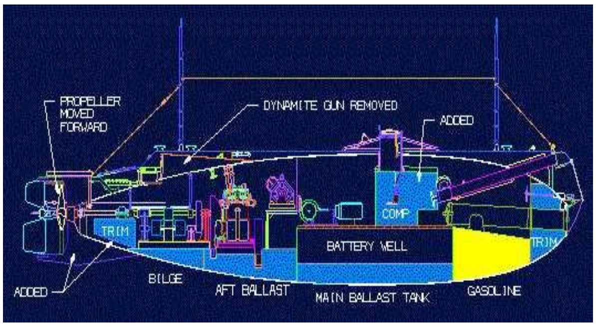


**Figure 1**. Ballas System at Submarine

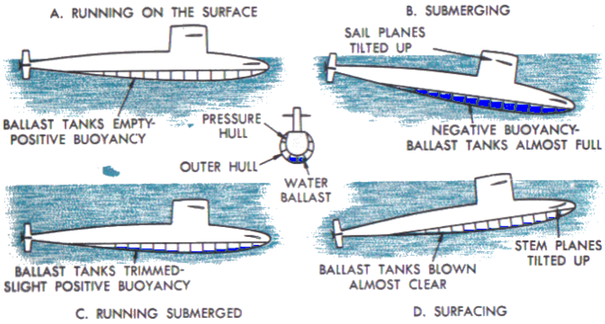


**Figure 2.** Submersion Proccess

Submarine is designed with the main ballast tanks fulls, the weight of water displaced will be as close as possible to the weight of the boat, see Fig.1. That is, there should be a balance between displacement and buoyancy, referred to as neutral buoyancy. If true neutral buoyancy is achieved the boat will float at whatever depth it presently is, unless something acts on it to make it rise or sink, see Figure 2. In practice, submariners prefer to maintain very slight positive buoyancy, so that if power if lost the boat may be expected to slowly rise to the surface.

In a quick dive, the negative tank is important. By flooding this tank the boat is made negatively buoyant, which gets the boat under water quicker. Once submerged, though, the negative tank is blown "to the mark." the submarine to be heavier than the water it displaced while diving, because you want to get under as quickly as possible.

## 2. Methods

*2.1 Floating Body Mechanism*

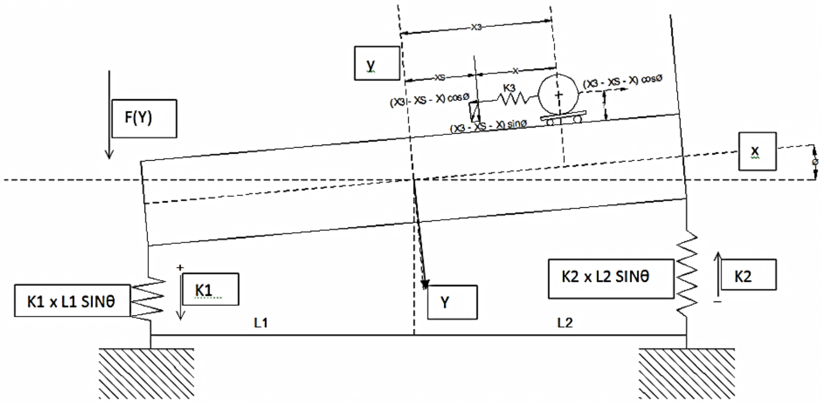


**Figure 3**. Floating Body Mechanism with Sloshing

In the pitching model system using 2 degrees of freedom, namely the mass beam or submarine described as the mass (M) ship and the mass of fluid in the ballast and described as two (2) spring of stiffness in the form of $k_1$ and $k_2$ for pitching motions, see Figure 3.
Mass of fluid in the tank load space is like a mass (m) in a moving train unhindered translational and 1 (one) spring of stiffness $k_3$ it also causes movement of the coupling to the model. If in the model gets a load (Fy) because of the influence of energy waves received by the model then the model will perform vertical and horizontal translation.
With the outside force that coordinates spring $k_1$ to the balance point (center of gravity) and is indicated for the spring $k_2$ toward the center of gravity is indicated $l_2$. With equation: $\sum F = m \times a$, and force coupling can be summarized as follows;

$k_1 l_1 - k_2 l_2$ So, $k_1 l_1 = k_2 l_2$

For fluid motion in the tank above the carriage modeled as a pendulum having stiffness without hindrance caused by the moving mass is equal to $k_3$ translansi as $(x_3 - x_s - x)sin\emptyset = (x_3 - x_s - x)cos\emptyset$.

Translation motion of fluid mass (m) will also affect the coupling pitch motion. The amount received by the vertical force spiral at an angle $\emptyset$ is;

$k_1\, l_1\, \emptyset = F_1$ has a positive direction (compressed) (1)

$k_2\, l_2\, \emptyset = F_2$ has a negative direction (pulled) (2)

So that the beam free motion coupled equations and moment caused due to a force from the outside of beam or submarine (Fy) and fluid in the ballast tank can be summarized as follows [4];

$$(M + m)\ddot{Y} = -2y(k_1 + k_2) - 2\emptyset(k_1.l_1 - k_2.l_2) - 2k_3(x_3 - x_s - x).(\sin\emptyset + \cos\emptyset) \quad (3)$$

$$(J + j)\ddot{O} = -2y(k_1.l_1 - k_2.l_2) - 2\emptyset(k_1.l_1^2 + k_2.l_2^2) - k_3(x_3 - x_s - x)$$
$$[(sin\emptyset.d) - \{(x_3 - x_s - x)cos\emptyset\}] \quad (4)$$

Where:
$k_1.l_1 - k_2.l_2$ is static Couple
$y = A\sin(\omega t + \varphi)$ serta $\emptyset = Csin(\omega t + \varphi)$ (5)
M is displasment ship
m is the mass of water in the fluid tank
$M\ddot{Y}$ is Fy is an external force due to wave energy
$m\ddot{Y}$ is the force due to sloshing
$\emptyset$ is the angle of the incident wave direction
J is moment due to an external force caused by wave
j is moment due to an internal force caused by fluids

*2.2. CFD (Computational Fluids Dynamic)*

Computational Fluid Dynamics (CFD) is the process of numerically solving fluid dynamics equations to predict resultant flow fields. It is used to model a rich variety of flow phenomena, as well as to define thermal and structural loads on bodies immersed in fluids[5].

The submarine is assumed to be traveling through an infinite domain of stagnant water. The motion of the submarine is controlled by a three-bladed propeller, rudder and stern planes. The entire computational mesh including the submarine body is assumed to be moving with the body without any deformation. The flow field computations were performed in the inertial frame of reference, which makes the specification of boundary conditions easier. Since the body moves through infinite volume of stagnant water, the velocity specified at the far field boundaries of the computational domain is zero.

For the case of horizontal overshoot maneuvering, held in this position until the body reached various pitch angle 6-14 degrees with speed 6 knots. Figure 7 to Figure 15 shows predicted pressure distribution on walls and streamlines around body for pitch motion.

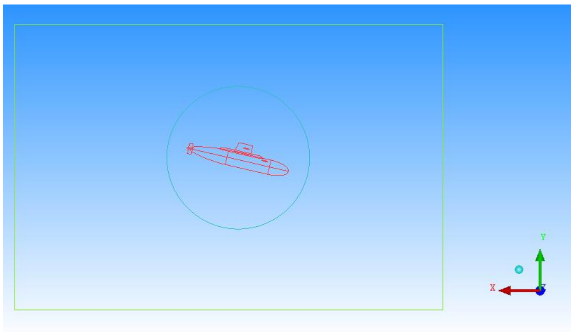

**Figure 4** Design model at ICEM CFD

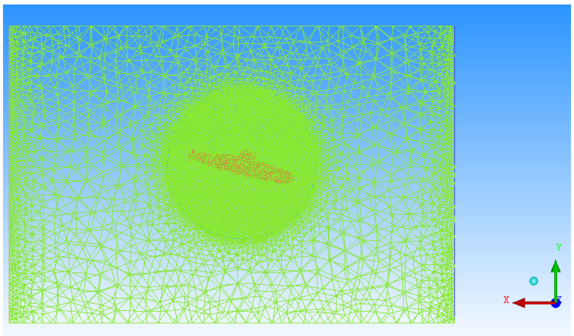

**Figure 5** Meshing Model

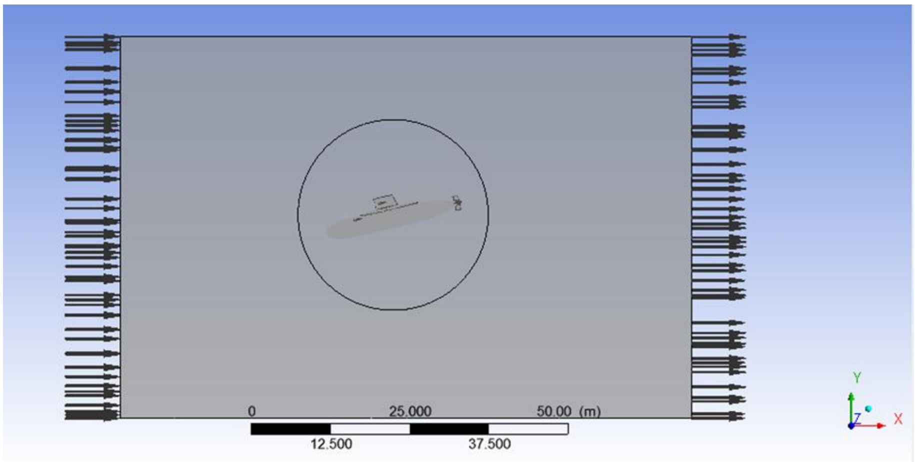


**Figure 6** Setting boundary for CFD Pre

As described above (Figure 3), it is assumed that the global fluid motion plays the most important role in the sloshing-induced impact occurrence. The incompressible Euler equation and continuity equation are the governing equations of the present method. To solve these equations, let us consider the discretization of the tank volume into finite meshes (Table 1) and as shown in Figure 3 for meshing model. Adopting the concept of the Cartesian staggered grid, the velocity components are defined on the cell boundaries, while the pressure is computed at the center of each cell. The simulation of a motion requires the coupled solution of rigid body motion equation (in six degrees of freedom) with unsteady Reynolds-averaged Navier-Stokes equations (URANS).

The integration and rigid body mesh motion are performed automatically using CD-adapco's Dynamic Fluid-Body Interaction (DFBI). In this case submarine move forward and acquire force of the front at angle $180^0$ (head seas), see figure 6.

**Table 1.** Generated Mesh Information

| Description | Meshing Specification |
|---|---|
| Object Name | Mesh |
| State | Meshed |
| Number of Nodes | 1358 |
| Number of element | 1314 |
| Number of Nodes (Diffracting Bodies) | 952 |
| Number of Elements (Diffracting Bodies) | 904 |

## 3. Result

In order to exercise the method developed above, submarine considered. A sketch of the submarine is shown in Fig. 7 to 15. The Submarine has the following geometric and mass properties: length = 22 m, reference diameter = 3 m, mass = 113.9 ton

As part of a validation of the coupled Navier-Stokes and six-degree-of-freedom method, time-accurate unsteady numerical computations were performed to predict the flow field, hydrodynamic coefficients, and the quick dive paths of submarine at an initial speed = 6 knots. Full three-dimensional computations were performed and no symmetry wall was used.

Here, the primary interest is in the validation of coupled CFD techniques for accurate simulation of free sailing and quick dive of submarine. Numerical computations were made for the submarine configuration at an initial velocity of 6 knots. The initial angle of attack (trim) was, $\alpha = 10^0$ Figure 9 shows the computed pressure contours at a given effective motion. It clearly shows the orientation of the body at that instant in time and the resulting flow field due to the body at angle of attack.

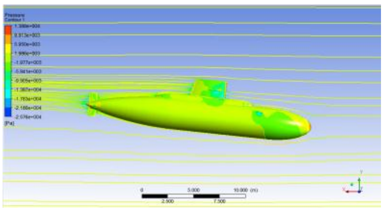

**Figure 7** Trim angle at $6^0$

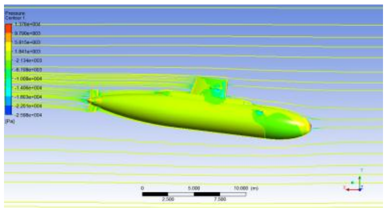

**Figure 8** Trim angle at $7^0$

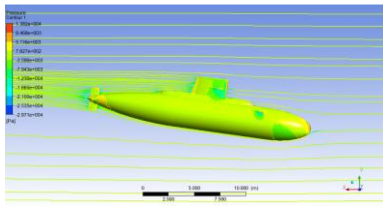

**Figure 9** Trim angle at $8^0$

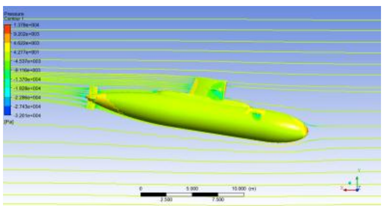

**Figure 10** Trim angle at $9^0$

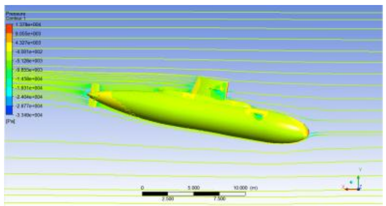

**Figure 11** Trim angle at $10^0$

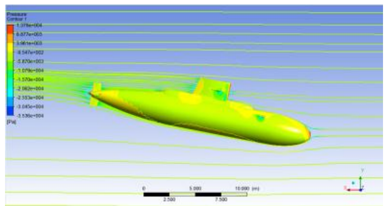

**Figure 12** Trim angle at $11^0$

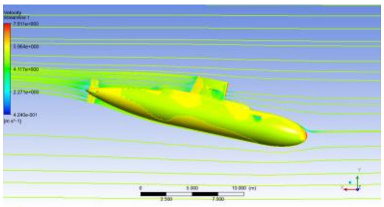

**Figure 13** Trim angle at $12^0$

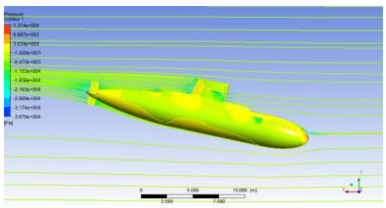

**Figure 14** Trim angle at $13^0$

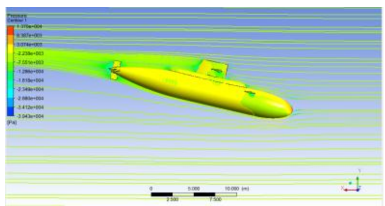

**Figure 15** Trim angle at $14^0$

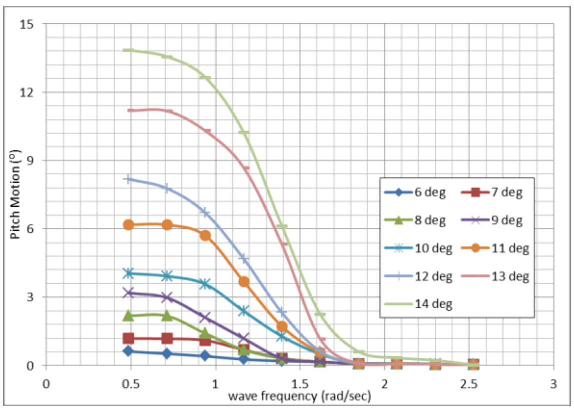


**Figure 16** Pitch motion in various angle

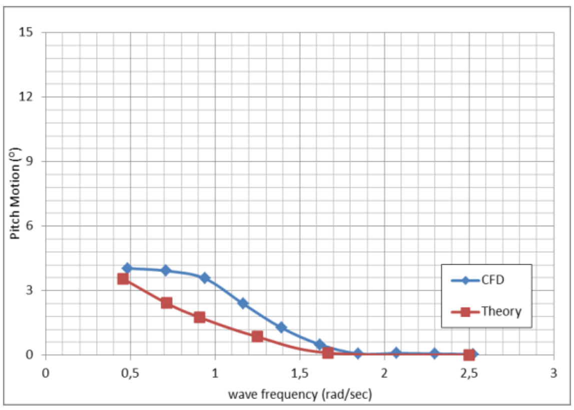


**Figure 17** Comparation Pitch Motion at angle $10^0$

## 4. Conclusion

In the present study, Theoretical and CFD of sloshing flows in ballast of submarine are described. Numerical methods, Free Floating Body Equation running by MAT-LAB version 6.5 methods, are applied to solve violent sloshing. Based on the present study, the following conclusions are made:

- The result of the CFD and Mathematical modeling is similar but RAO for CFD the numerical due to some impact like damping force and added mass. CFD and Theoretical analysis shown same trend both on $180^0$ of pitch.
- At wave heading $180^0$ which cause pitching significant consequences sloshing of 50% in mass (m).
- The sloshing-induced force and moment are not linearly proportional to excitation amplitude. Therefore, the submarine motion with sloshing does not vary in a linear manner with respect to wave amplitude.

The vessel had effective angle of inclination when diving was 10° when submerged the speed of 6 knots after the required depth had been obtained this angle became so small as to be inappreciable and had to be maintained to keep effective depth control.

## 5. References

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