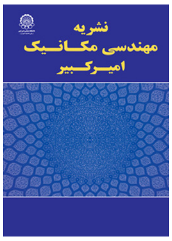

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Experimental and Numerical Study of a Submerged Submarine Moving Near the Free Surface

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ABSTRACT: Resistance and wave pattern due to the motion of an underwater vehicle model are obtained by experimental and numerical methods. The tests on the model are carried out in Shohada-e-Khalij-e-Fars National Marine Laboratory. The model is towed with the carriage at various speeds and two depths of submergence in the basin. The model is made from polyethylene and is attached to the carriage by a strut at the end. The strut at the end allows to measure the wave pattern of the body alone but the measured resistance is for the body and the strut. The computational fluid dynamics is used to study the interaction of body and strut and the resistance of the body is obtained by eliminating the effect of the strut. The wave profile is measured by four fix sensors at the transverse section of the basin. The wave profile is also obtained by computational fluid dynamics computations and compare with the experimental measurements. The numerical and experimental results are comply with each other. These experimental results can be used to validate and calibrate the numerical solutions.

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1- Introduction

The force from air and water acting on a marine vehicle moving along a straight line in the longitudinal direction is called resistance. The resistance is due to the effect of the viscosity of water and air and the formation of waves on the free surface. Resistance of a marine vehicle may be obtained by model testing in a hydrodynamic lab or by numerical calculations.

There are various numerical methods to find the resistance of a marine vehicle. Nowadays, the use of numerical methods based on RANS models are growing to find the resistance and other hydrodynamic properties of marine vehicles. It is necessary to have valid experimental results to control and calibrate the numerical computations. There are quite plenty of experimental data for surface vessels but quite limited valid experimental results for submarines and most of them is for SUBOFF model such as Roddy [1] and Liu [2].

A set of experimental results are developed for resistance of a Joubert submarine model moving near the free surface of water. Since the submarine is connected to the carriage with a strut behind the hull, a method based on the Computational fluid dynamics (CFD) computations are presented to remove the effect of the strut and find the resistance of the model alone. The profile of the surface elevations are measured experimentally.

2- Methodology

The resistance and wave profile of a Joubert submarine model, as shown in Fig. 1, are measured at Shohada-e-Khalij-e-Fars National national Marine marine Laboratorylaboratory. This lab has a long basin with dimensions 400×6×4 m. The basin is equipped with a carriage to tow the marine vehicle model. The carriage has two speed modes of maximum 5 and 19 m/s The lab is originally designed to test ships and fast boats models and is not equipped with the facilities to test underwater vehicles. A strut is designed and built to connect the submarine model to the carriage. The model has been tested in two dimensionless depth of $D^*=H/D=1.3$ & 2.2 and six different speeds of v=0.88, 1.1, 1.3, 1.53, 2.19 and 3.3 m/s. The notation H is the depth of submergence and D is the submarine diameter. The strut has been also tested alone at these speeds and depths alone.

The interaction between the strut and the body has been

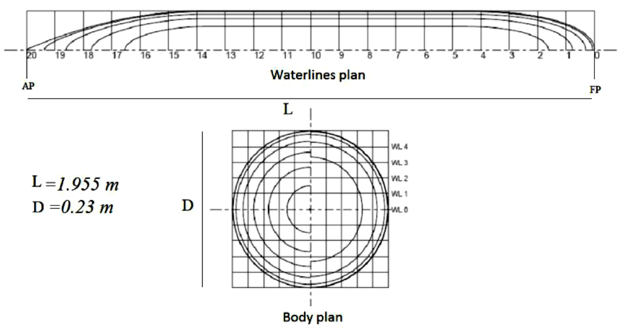

Fig. 1. Dimensions and the body lines of the Joubert submarine model [3]

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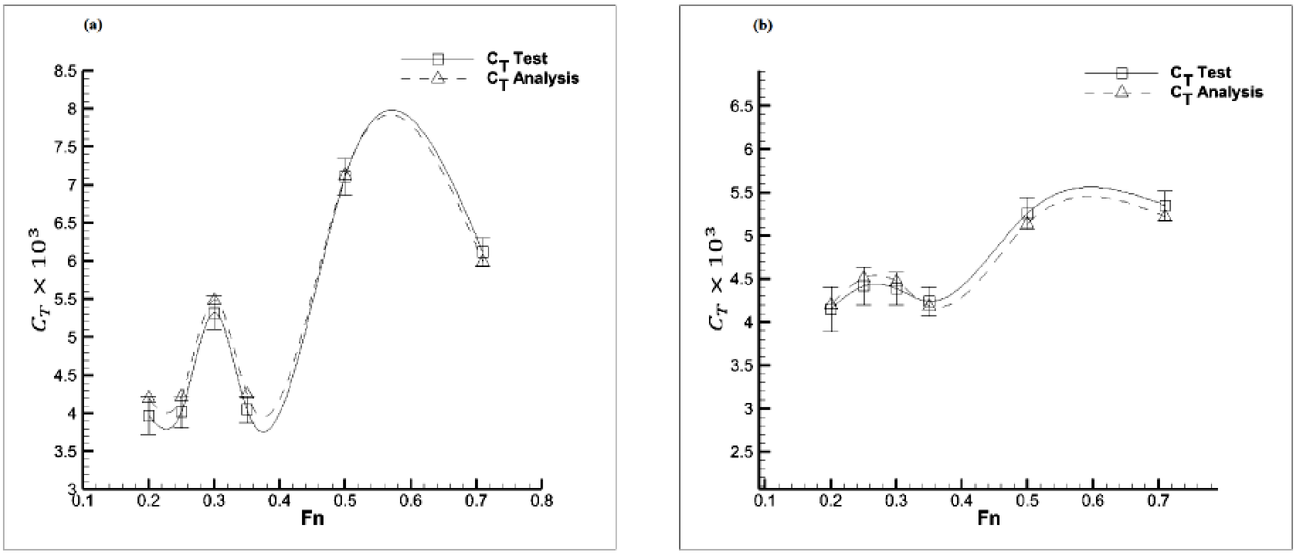

Fig. 2. The resistance coefficient of model with strut at D^*, a:1.3, b:2.2

studied and analyzed using computational fluid dynamics. The flow is modeled around the body, the strut and the body with strut by the Star CCM+CFD software to find the resistance and wave profile at all speeds and two different depths. The *k-ε* standard turbulent model with Volume of Fluid (VOF) method have been used in CFD analysis. For more explanation about CFD computations, refer to Shariati and Mousavizadeghan [4]. The effect of the strut on the resistance are obtained by comparing the experimental and computational results. The valid experimental results for the submarine model at various speeds and depths are presented by removing the effect of the strut.

3- Results and Discussion

The resistance coefficient is defined by $C_T=2R_T/\rho S v^2$ where R_T is the resistance, ρ is the fluid density and S is the model wetted surface. The experimental results is are measured by a sensor between the strut and the carriage and therefore, the data shows the resistance of the model with strut. The numerical solutions for model with strut are also calculated numerically. The experimental and numerical results of C_T are presented in Fig. 2 as a function of F_n at two non-dimensional depths for body with strut. The numerical solutions are comply with the experimental results and the differences between them are at most 8.5% which is in the range of experimental uncertainties. The resistance coefficient has humps and hollows especially at D^*=1.3. It is due to the interference effect of waves that are formed due to the motion of body on the free surface.

The effect of the strut in the test results should be eliminated

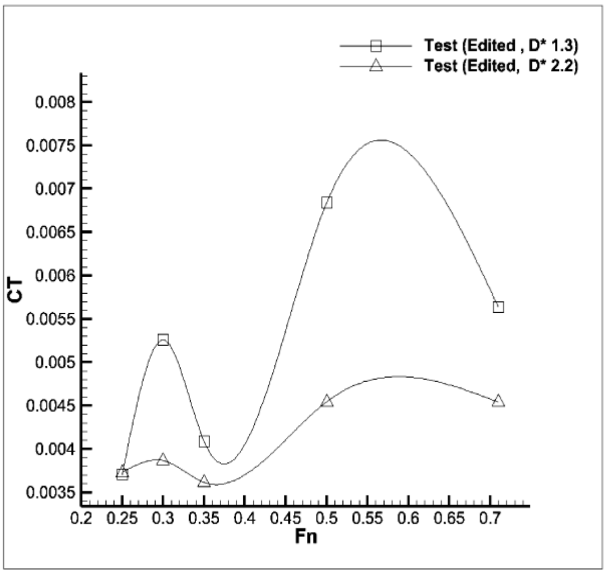

Fig. 3. The model resistance coefficient

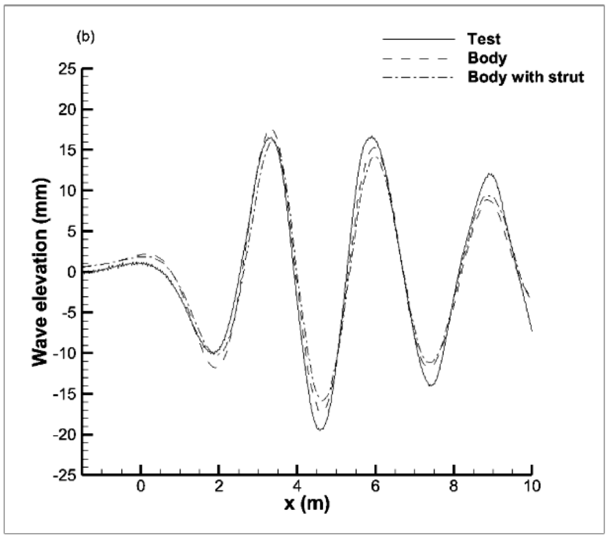

Fig. 4. Free surface changes observed in the test, model analysis and model analysis with the strut at speed of 2.19 m/s and D^* 2.2.

to find the experimental data for submarine model. It can be done if the force sensor is placed inside the model, between the model and the strut. In this case, the sensor only measures the force acting on the model. This is not currently practical with existing laboratory facilities. However, it should be taken into account that the flow around the strut behind the model is affected by the wake of the model.

The numerical computation is used to obtain the experimental result for the submarine model by finding a correction factor that is denoted by *C*. The model resistance coefficient is obtained by:

$$C_{Tm} = C_T - \left(C_{Ts} - C\right) \quad (1)$$

where C_{Tm} is the model resistance coefficient, C_T the model and strut resistance coefficient and C_{Ts} is the strut resistance coefficient. The correction factor for this model of strut is 0.0007. The model resistance coefficient is given in Fig. 3 for both depths at various F_n by considering the strut correction factor.

The wave height has been recorded by four wave sensors that are located in tank width. The recorded wave profile at sensor 1 are compared with the results of computations for the model and model with strut in Fig. 4. There is a good agreement between experimental and numerical results and the strut does not affect the waveform near the model. At far field, due to the effect of the strut and the wave reflection by towing tank wall, the shape of the free surface has completely changed and overall differences between experiments and analysis are observed.

4- Conclusions

Resistance force and wave profile of a Joubert submarine model moving near the free surface are studied experimentally and numerically. The model is tested at two submergence depths and six different speeds. The numerical computations are done by Star CCM+ software CFD package. The computations are done for the body and the body with the strut at both submergence depths. The results of resistance force and free surface profiles measured in the laboratory are presented as reference results for calibration and validation of near the free surface analysis. Comparison of experimental and numerical results of the model with the strut, showed that the chosen analysis method has the ability to analyze the resistance of a submerged vehicle near the surface. The effect of the strut on the resistance is nonlinear and a correction factor is obtained to remove the effect of the strut from the experimental measurements. The strut does not affect the wave formation near the body. The wave formation at the far field is affected by the presence of the strut and wave reflection by the basin walls.

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