Design and Analysis of Submersible Vehicle with Water Jet Propulsion System

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Abstract— The present-days submersible vehicle travel at a maximum speed of 35 knots (65 km/h or 40 mph) and some could attain a short speed burst of 40-45 knots (75-84 km/h or 46-52 mph) while submerged. In order to extract resources available from oceans, seas, etc., or to travel at high speeds at underwater there is a need for the development of high efficient propulsion system and well-designed submersible vehicles which can overcome the underwater drag effects which reduce the speed of the vehicle. This paper aims at developing water jet thruster and a submersible vehicle which can propel at greater speeds by reducing the effects of drag and pressure. The design for such a water jet thruster and a geometric model of submersible vehicle is carried out in Solidworks and analyze using CFD and flow simulation is carried out in Solidworks Flow Simulation. Parameters like drag coefficient, pressure and velocity variations that affect the submersible vehicle and water jet thruster are studied. These parameters are evaluated using FVM and using Cartesian-based CFD meshing.
Key words: CFD, Flow simulation, FVM, Submersible Vehicle, Water Jet Propulsion System

I. Introduction

Underwater vehicles applications have been expanding and are used even for the ocean research and development, scientific investigations and for defence, etc. The development of underwater vehicles reached a level of technological maturity. However, one of the largest design considerations of these underwater locomotives that have a specific mission scenario is the propulsion system and vehicle geometry. Propulsion system affects the vehicle's maximum and minimum speeds, power storage systems, the cost of production, etc. The hydrodynamic parameters such as drag coefficient, pressure contours, and velocity contours depend on the geometry of the vehicle which affects the speed of the vehicle.

In this paper, we detail the key objectives in the design process and the underlying theory behind water jet propulsion system and submersible vehicle and present a new design of high-speed submersible vehicle with a new type of propulsion system.

II. Governing Equations

The Navier – Strokes equations which are formulations of mass, momentum, and energy conservation laws are solved.

A. *Conservation of mass (Continuity equation):*

The conservation of mass principle states that in the absence of mass sources and sinks, a region will conserve its mass on a local level. It is given as:

$$\frac{\partial \rho}{\partial t} + \nabla.[\rho\vec{v}] = 0 \qquad (1)$$

Where ρ is the density and v is the velocity of the fluid.

B. *Conservation of momentum:*

The conservation of momentum principle states that in the absence of any external force acting on a body, the body retains its total momentum (product of its mass and velocity). It is given as:

$$\rho\left[\frac{\partial \vec{v}}{\partial t} + (\vec{v}.\nabla)\,\vec{v}\right] = f \quad (2)$$

Where f is the external force per unit volume acting on the material volume.

C. *Conservation of energy:*

It is governed by the first law of thermodynamics which states that energy can be neither created nor destroyed during a process; it can change from one form into another. It is given as:

$$\frac{\partial}{\partial t}(\rho e) + \nabla.[\rho\vec{v}e] = -\nabla.\left(\sum_j h_i J_j\right) + S_h \qquad (3)$$

III. Methodology

A. *Design of Water Jet Propulsion System:*

A water jet propulsion system designed is as shown in Figure 1.

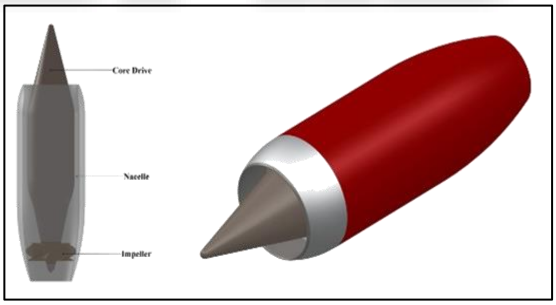

Fig. 1: Water Jet Propulsion System

It consists of three main parts namely core drive, nacelle, and impeller. The core drive consists of an electric motor which is connected to the impeller. Nacelle holds the core drive and impeller. Specifications of the impeller are listed in Table 1.

Number of discs	3
Diameter (D)	150 mm
Pitch (P)	330 mm
P/D	0.454
Rotation	Right hand rotation
Rake	Positive

Table 1:

B. *Design of Submersible Vehicle:*

The geometry of submersible vehicle is based on the deep sea living creature, the blue whale which can survive at greater depths at high pressures. The geometry of submersible vehicle is as shown in Figure 2.

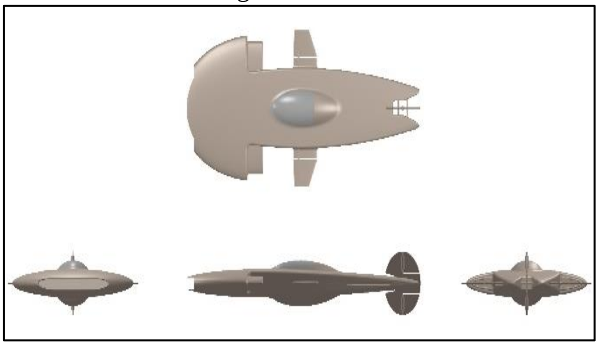

Fig. 2: Submersible Vehicle

C. *Meshing of models:*

The meshing of models is done in Solidworks Flow Simulation software. Finite volume methods are used in the generation of meshes and for CFD analysis. The cells are in the shape of a cuboid. The Cartesian immersed body mesh type of meshing is used in the generation of the grid. The cell count is as shown in Table 2.

Model	Fluid cells	Solid cells	Partial cells	Total cells
Water Jet Propulsion system	384992	79858	58882	464850
Submersible vehicle	453734	8425	5912	462159

Table 2:

D. *Simulation parameters:*

The flow parameters including initial and boundary conditions for the water jet propulsion system and submersible vehicle follows as shown in Table 3.

Parameters	Water Jet Propulsion system	Submersible vehicle
Solver	Pressure based steady state	Pressure based transient state
Turbulence model	$k-\varepsilon$	$k-\varepsilon$
Velocity (m/s)	20.600	0-65
Initial pressure (Pa)	5022720.00	5022720.00
Initial temperature(K)	293.20	293.20
Boundary type	Real wall	Real wall

Table 3:

IV. RESULTS AND DISCUSSIONS

The CFD analysis is done using viscous flow conditions with water as a fluid applying real wall conditions. Results such as drag coefficient, drag forces are plotted as follows:

A. *Water Jet Propulsion System:*

The results consist of plots for drag coefficient, drag force and minimum and maximum tables for different parameters. The plots are shown below:

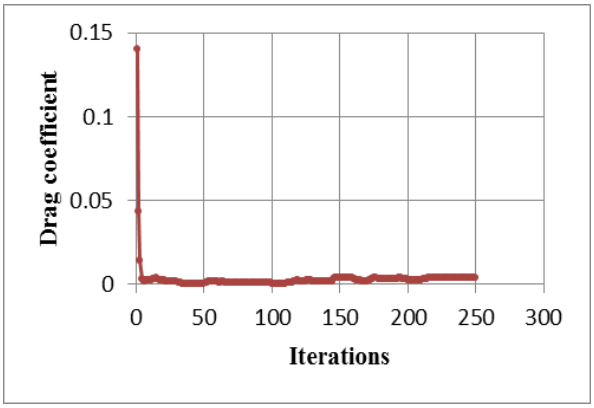

Fig. 3: Drag coefficient

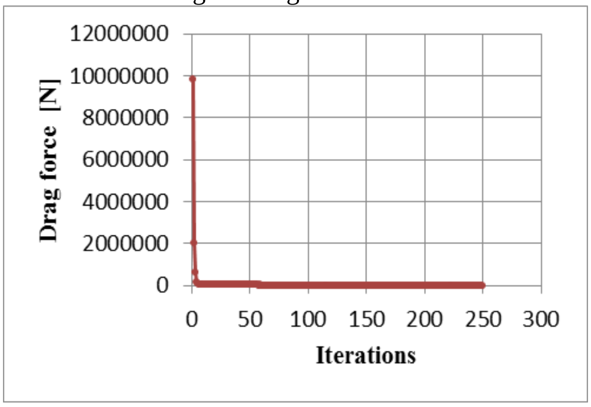

Fig. 4: Drag force

The minimum and maximum values of different parameters for all iterations are tabulated in Table 4:

Parameter	Minimum	Maximum
Density (Fluid) [kg/m^3]	997.55	997.57
Pressure [Pa]	1540953.08	9098274.16
Temperature [K]	293.15	293.25
Temperature (Fluid) [K]	293.15	293.25
Velocity [m/s]	0	26.916

Table 4:

Pressure and velocity cut plots are as follows:

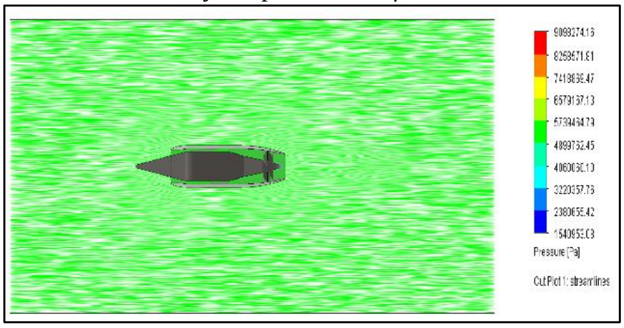

Fig. 5: Pressure cut plot

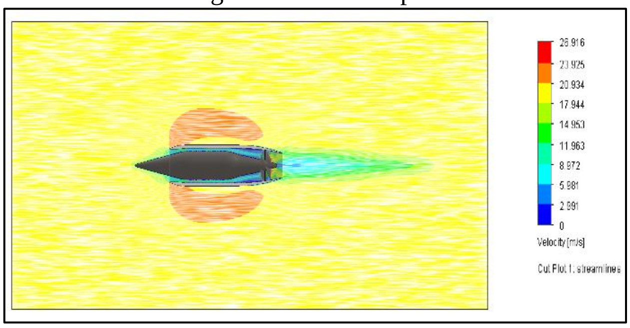

Fig. 6: Velocity cut plot

B. Submersible vehicle:

The results consist of plots for drag coefficient, drag force and minimum and maximum tables for different parameters. The plots are plotted against different time steps since it is transient flow analysis.

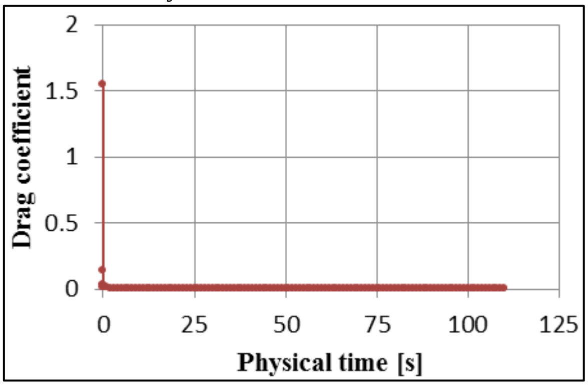

Fig. 7: Drag coefficient

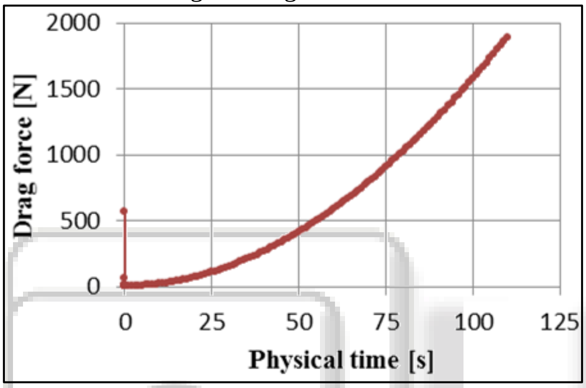

Fig. 8: Drag force

The minimum and maximum values of different parameters for all iterations are tabulated in Table 5:

Parameters	Minimum	Maximum
Density (Fluid) [kg/m^3]	997.47	997.60
Pressure [Pa]	4936802.50	5220465.21
Temperature [K]	293.03	293.56
Temperature (Fluid) [K]	293.03	293.56
Velocity [m/s]	0	62.164

Table 5:

The surface pressure distribution is shown in Figure 9 and initial and final velocity contours are shown in Figure 10 and Figure 11.

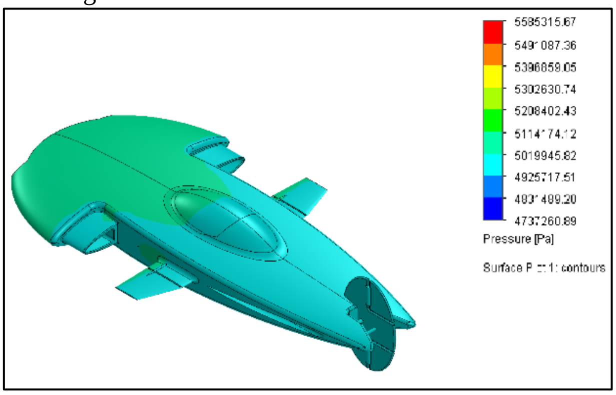

Fig. 9: Surface pressure distribution

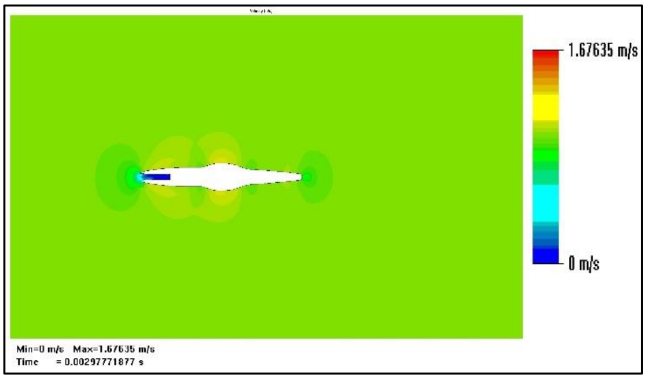

Fig. 10: Initial velocity contour

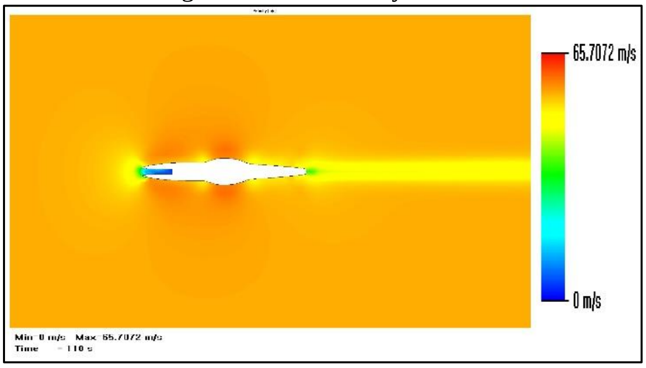

Fig. 11: Final velocity contour

C. Interpretation of results:

From the computed results it can be observed that the submersible vehicle is able to travel at higher speeds approximately equal to 62 m/s. The drag force increases with increase in speed.

V. CONCLUSION

The hydrodynamic effects on water jet propulsion system and the submersible vehicle such as drag coefficients, drag force are studied and velocity and pressure variations are calculated using Solidworks Flow Simulation software. The study gives the following conclusions:

1) The replacement of propeller with the impeller in water jet propulsion system successfully sustained and gives better results.
2) The submersible vehicle design is tested up to a speed 62 m/s which is greater than currently available same class vehicles.

REFERENCES

[1] Oskar Levander, Susanna Hannula, "Propulsion System of Marine Vessel," United States Patent, Patent N0.: US 20080009208 A1.

[2] Andrew H. REBELE, Christopher M. Gil, Kerwin M. LOUKUSA, Matthew M. O'Brien, Zachary Meyer Omohundro, Nathan SCHROEDER, "Stern board drive for marine electric propulsion with speed control and wireless communication connectivity," United States Patent, Patent N0.: US 20140327347 A1.

[3] Ole Arnt Marholm, Gunnar Johnsen, Dag Brandal, "Thruster unit and method for installation of a thruster unit," United States Patent, Patent N0.: US 20130040514 A1.

[4] G.T. Reader, "The Evolution of AUV Power Systems," 2002.
[5] P.K. Poole, "A systems approach to autonomous underwater vehicle (AUV) propulsion."
[6] James A. Schultz, "Autonomous Underwater Vehicle (AUV) Propulsion System Analysis and Optimization," Virginia Polytechnic Institute and State University, Blacksburg, Virginia, May 4, 2009.