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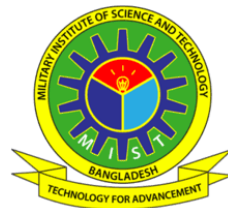
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DEVELOPMENT OF A DIVER PROPULSION VEHICLE SIMULATOR FOR SEARCH AND RESCUE OPERATION

MOHAMMED NAZMUL HAQ

M. ENGINEERING THESIS



**DEPARTMENT OF MECHANICAL ENGINEERING
MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY
DHAKA, BANGLADESH**

JUNE 2023

DEVELOPMENT OF A DIVER PROPULSION VEHICLE SIMULATOR FOR SEARCH AND RESCUE OPERATION

MOHAMMED NAZMUL HAQ (0419180013)

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master
of Engineering in Mechanical Engineering



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DEVELOPMENT OF A DIVER PROPULSION VEHICLE SIMULATOR FOR SEARCH AND RESCUE OPERATION

DECLARATION

I hereby declare that the study reported in this thesis entitled above is my original work and has not been submitted before for any degree or other purposes. Further, I certify that the intellectual content of this thesis is the product of my work and that all the assistance received in preparing this thesis and sources have been acknowledged and/or cited in the reference Section.

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ABSTRACT

Development of A Diver Propulsion Vehicle Simulator for Search and Rescue Operation

Diver Propulsion Vehicle (DPV) is a self-propelled device used to facilitate divers to move freely underwater for search and rescue operations as well as for exploration purposes. DPV provides speed and a long-range to cover a wide area for various diving operations. A DPV generally consists of a pressure-resistant waterproof casing with a battery-powered electric motor that drives the propeller. It is widely used across the globe very effectively with a varying range of design and endurance capabilities. The design and fabrication of DPVs have been done in many developed countries. Indigenous design and fabrication of DPV are possible by utilizing local resources of Bangladesh. Designed prototype DPV is developed using SolidWorks, and a CFD analysis is carried out using Ansys software. After that, a DPV model is fabricated using resources from the local market. This project preliminarily focused on design, fabrication of DPV and simulated various parameters to get better results. Finally, the test and trial results and performance of the DPV are evaluated so that it can be used effectively for search and rescue operations in Bangladesh.

সারসংক্ষেপ

Development of A Diver Propulsion Vehicle Simulator for Search and Rescue Operation

ডাইভার প্রপালশন ভেহিকেল (ডিপিভি) একটি স্ব-চালিত যন্ত্র যা ডুবুরিদের অনুসন্ধান এবং উদ্ধার অভিযানের পাশাপাশি তত্ত্বানুসন্ধান-এর উদ্দেশ্যে অবাধে পানির নিচে চলাচলের সুবিধার্থে ব্যবহৃত হয়। ডিপিভি বিভিন্ন ডাইভিং অপারেশনের জন্য একটি বিস্তৃত এলাকা কভার করার জন্য গতি এবং একটি দীর্ঘ পরিসর প্রদান করে। ডিপিভি সাধারণত একটি চাপ-প্রতিরোধসম্পন্ন জলরোধী আবরণ (pressure-resistant waterproof casing) এর মধ্যে রক্ষিত একটি ব্যাটারি চালিত বৈদ্যুতিক মোটর (battery-powered electric motor) যা একটি প্রপেলারকে শক্তি প্রদান করে চালনা করে। বিভিন্ন ধরনের ডিজাইন এবং সহনশীল ক্ষমতা সম্পন্ন এ ধরনের জলযান বিশ্বজুড়ে ব্যাপক ও কার্যকরীভাবে ব্যবহৃত হয়ে আসছে। এ দেশের স্থানীয় সম্পদ ব্যবহার করে নকশা প্রনয়নের মাধ্যমে দেশীয় প্রযুক্তিতে ডিপিভি উৎপাদন করা সম্ভব। উপরোক্ত বিষয়াদি বিবেচনায়, একটি ডিপিভি প্রোটোটাইপ ডিজাইন করা হয় এবং সলিড ওয়ার্কস (SolidWorks) ব্যবহার করে একটি ত্রি-মাত্রিক মডেল (3D Model) তৈরি করা হয় এবং এ্যানসিস (Ansys) সফটওয়্যার ব্যবহার করে একটি সিএফডি (CFD) এ্যানালাইসিস করা হয়। অতপর, স্থানীয় বাজার থেকে সম্পদ ব্যবহার করে একটি মডেল ডিপিভি (model DPV) তৈরি করা হয়। এই প্রকল্পটি প্রাথমিকভাবে প্রোপেলার সহ ডিপিভি সিমুলেশনের উপর গুরুত্ব আরোপ করে। অতপর, টেস্ট-ট্রায়াল (test and trial) শেষে ডিপিভি এর কর্মক্ষমতা মূল্যায়ন করা হয়। পরিশেষে, বাংলাদেশে অনুসন্ধান ও উদ্ধার অভিযানের (Search and Rescue) জন্য ডিপিভিটি কার্যকরভাবে ব্যবহার করা সম্ভব বলে প্রতীয়মান।

LIST OF MAIN ABBREVIATIONS

AUV	Autonomous Underwater Vehicle
BN	Bangladesh Navy
BoB	Bay of Bengal
BCG	Bangladesh Coast Guard
Coord	Coordinator
CAD	Computer-Aided Design
CFD	Computational Fluid Dynamics
DC	Direct Current
DCE	Defense Consulting Europe
DPV	Diver Propulsion Vehicle
DSC&SC	Defense Services Command & Staff College
FVM	Finite Volume Method
GFRP	Glass Fiber Reinforced Plastic
GPS	Global Positioning System
HMS	Her Majesty Ship
IR	Infra-Red
Kt	Nautical Mile per hour
Kts	Nautical Miles per Hour (Knots)
MCM	Mine Counter Measure

MRCC	Multi-Role Combatant Craft
NPS	The National Park Service
nm	Nautical Mile
PTFE	Poly Tetra Fluro Ethylene
R&D	Research and Development
RIB	Rigid-hulled Inflatable Boat
ROV	Remotely Operated Vehicle
RPM	Revolution Per Minute
RWSV	Remote Weapon Station Vehicle
SAR	Search and Rescue
SEAL	Sea, Air, and Land
SDV	Swimmer Delivery Vehicle
SOP	Standard Operating Procedure
SWCS	Shallow Water Combat Submersible
TNT	Trinitrotoluene
USS	United States Ship
UUV	Unmanned Underwater Vehicle
VHF	Very High Frequency
WWII	World War II

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Diver Propulsion Vehicle (DPV) is a battery-powered mechanical device used to facilitate divers to move freely underwater for Search and Rescue (SAR) operations as well as for exploration purposes. DPV provides speed and a long-range to cover a wide area for various diving operations. A DPV generally consists of a pressure-resistant waterproof casing with a battery-powered electric motor that drives the propeller. DPVs are widely used across the globe with varying ranges of design and endurance capabilities very effectively.

The design and fabrication of DPVs is going on in many developed countries. Indigenous design and fabrication are possible by utilizing local resources of our country at a very low cost.

From the above perspective, a DPV prototype/simulator is designed and fabricated for the project. This paper focuses preliminarily on the design phase of the DPV Simulator including the propeller. Finally, the test and trial results and performance of the DPV have been evaluated and a few recommendations are made including the possibility of modification of the DPV in the future.

1.2 Problem Statement

Bangladesh has a wide coastal and sea area in the Bay of Bengal (BoB). Search and rescue operation in the coastal areas including sea is a challenge for the maritime forces specially Bangladesh Navy (BN) and Bangladesh Coast Guard (BCG). Furthermore, Bangladesh is vulnerable to many natural disasters and calamities round the year, including mishaps on the waterways. It takes time and involves risks for rescuers to prepare and send a team for search and rescue operation, delay of which occasionally results in fatalities. Also, evacuation of injured personnel is to be done in time to save lives and recover valuable materials as well. Therefore, the use of DPV during the search and rescue operation to facilitate and support saving of lives of many people in distress is felt including recovery of valuables.

Laying mines at the bottom of the enemy ships or harbors in silent hours is a dire need though challenging and dangerous task for the divers during a war scenario. A DPV may be used effectively for placing mines beneath enemy ships or harbors during a war situation.

Divers of Civil organizations need suitable platforms during search and rescue operations. A DPV can be extensively used by civil divers during search and rescue operations.

Tourists need suitable platforms during underwater exploration. A DPV can be extensively used by tourists in clear water during exploration underwater.

The design and development of DPV is carried out in many countries for search and rescue operations including explorations. However, they are very expensive, and hence they are not imported in Bangladesh. Therefore, it is important to design and create a DPV prototype that will allow in-house design and development at a very low production cost. There are many areas where DPV can be used, particularly for search and rescue operations and underwater exploration.

A DPV can be effectively utilized for the search and rescue operation by divers of Bangladesh Navy, Bangladesh Coast Guard and other maritime agencies. Hence, the goal is to design and develop a Diver Propulsion Vehicle (DPV) for effective use in the search and rescue operation without endangering human life. However, the following problems can be used to describe the problem statement:

- a. Divers need a suitable platform to carry themselves together with items required for survivors during search and rescue operations. DPV can be extensively used as a suitable platform for divers during search and rescue operations.
- b. Laying mines at the bottom of the enemy ships or harbors in silent hours is a dire need though challenging and dangerous task for the divers during a war scenario. A DPV may be used effectively for placing mines beneath enemy ships or harbors during a war situation.
- c. Divers of Civil organization do not have suitable platforms during search and rescue operations. DPV can be extensively used by civil divers during search and rescue operations.
- d. Tourists don't find suitable platforms during underwater exploration. DPV can be extensively used by tourists in clear water during exploration underwater.

1.3 Motivation

All those issues were not addressed in an integrated way before. Bangladesh Navy, Bangladesh Coast Guard and other maritime organizations may efficiently conduct the

search and rescue operation using DPV. This DPV will significantly reduce the risk of operation and enhance the efficiency of present capabilities. The country can face waterborne human or material casualties faster. In addition, motivation for this project also includes the following issue:

‘We can reach more waterways with the help of this DPV.’

This capacity will undoubtedly speed up the evacuation or recovery process of human victims and reduce casualties. The use of DPV will eventually reduce the restrictions and challenges of search and rescue in isolated coastal locations. The idea of laying a mine at the bottom of enemy ships or harbors during war situation is also very motivating.

The design and fabrication are made at a low cost as it is in-house designed and developed. It is customized and easy to design hardware and software as the components and electronics used were solely sourced from the local market. However, the working principle of the DPV is also simple and easy for maintenance.

A system with very low noise and minimum or no wake enables a diver to work silently and covertly without being detected by the enemy. As a result, the system is incredibly precise and safe for use during search and rescue operations, especially during mine laying operation at war.

The DPV is very easy to operate because of its simple mechanism and better output. During its operation, communication can be made with the diver operating the DPV. In underwater, the Infra-Red (IR) cameras can assist in better vision and can enhance better accuracy of the operation of the DPV. The DPV can also be equipped with GPS, Depth Gauge, Search Light and other useful gadgets to facilitate divers for search and rescue operations. The DPV when controlled remotely, can also be used to acquire relevant data as part of Ocean Observation activities in the near future.

1.4 Objectives of the Project

The objectives of the project are as stated bellow:

To design a DPV Simulator using Computer Aided Design (CAD).

- a. To validate the design using ANSYS software.
- b. To fabricate the model DPV and to evaluate its performance.

1.5 Project Paper Outline

This section is about how this thesis report is organized and what contents are in the chapters. The chapter-wise contents are appended below.

In Chapter 2, some points related to our project literature review are discussed. In this chapter introduction, application and the brief history of DPV have been discussed.

In Chapter 3, the prospect of DPV in Bangladesh including workshop support, skilled workers and test and trial have been discussed to assess the fabrication prospect of DPV in Bangladesh.

In Chapter 4, some points related to the methodology like initial concept design of DPV, model design validation, design finalization, fabrication, assembly, test-trial and evaluation of performance have been discussed.

In Chapter 5, some points related to the design of DPV, buoyancy control, hydrostatics, hydrodynamics and Bernoulli's equation, drag, ducted propeller, base drag, computational fluid dynamics (CFD), sealing, reduction gear, design parameters of DPV, project implementation plan have been discussed.

In Chapter 6, the design validation, computational fluid dynamics (CFD) evaluation, design and tools aspects, mesh properties, solver setup, material assignment, CFD results with analysis have been discussed.

In Chapter 7, fabrication of body and propeller of DPV, fabrication machinery, hull fabrication, selection of propeller and assembly have been discussed.

In Chapter 8, design of electrical system of DPV, electrical components, run time calculation, electrical component diagram, cautions, assembly of mechanical and electrical component have been discussed.

In Chapter 9, evaluation of performance, test data, findings, various tests and performance, specification and comparison of the new DPV with commercial DPVs have been discussed.

In Chapter 10, conclusion and recommendations regarding the DPV have been discussed.

CHAPTER 2 LITERATURE REVIEW

2.1 Literature Review

Anam H. et al. (2015) carried out simulation studies to produce data in the form of comparison between DPV without tunnel, with side tunnel, bottom tunnel. The results were presented as data containing surface pressure, environmental pressure, cut plot speed, and 3-dimensional flow velocity and drag force. The software used in this simulation is SolidWorks 2014 by utilizing flow simulation toolbox. Simulations were carried out by input parameters, with a depth of 30 m or conditions of a pressure of 4 atm. The input velocity of 3 m/s was given for various design configurations: without tunnel, side tunnel, bottom tunnel. For the purpose of analysis, plots were generated in the form of forces and moments in the x, y, and z-axis, the pressure at the surface of the DPV Ganendra RI-1, the environment pressure, as well as the maximum speed that could be achieved by DPV Ganendra RI-1 for all three different designs. From the data analysis, the side tunnel design provides the overall best performance to achieve desired vehicle specification.

Gungor E. and Ozdemir I. B. (2015) carried out Cavitation tunnel tests of two types of conventional propeller (namely P-4382 and P-4119). The characteristic performances of those were all compared with CFD analysis for different conditions to realize the effects of mesh generation, discretization method and turbulence model in numerical process. Design criteria for unique propeller were selected according to underwater vehicle performance and its requirements. Then the method performed in validation stage was entirely implemented to the new design to observe its performance curves. The results showed that the new propeller design was capable of providing desired thrust, vehicle velocity and power output with high efficiency for underwater vehicle. Algorithm implementation, mesh generation, turbulence models and solution methods in CFD process were so suitable that results of analyses were matching with experiments.

Anam H. et al. (2017) manufactured A Diver Propulsion Vehicle (DPV) Ganendra RI-1, also known as an underwater propulsion vehicle or underwater scooter is an item of equipment used by scuba divers and rebreather divers underwater to increase the range. The final stages of design, analysis, manufacturing, and performance test of the DPV were done. The design was completed to determine mechanical, electrical, and propulsion

systems. Performance of DPV was found as the maximum thrust up to 50 kgf using 48 Volt and 80 Ah lithium-Fe battery. Maximum speed of DPV was 3.5 knots with endurance up to 3 hours having an operational depth up to 7 meters.

Later, Anam H. et al. (2017) developed another Diver Propulsion Vehicle (DPV) Ganendra RI-1 MK. II using material fiber reinforced composite. The manufacturing process employed for this product was Vacuum Assisted Resin Infusion (VARI) process. The ultimate tensile test of the prototype's shell (GFRP) was 330.45 MPa. The prototype accomplished 150 mins dive at an average speed of 3.5 knots without any leakage.

DPVs are the effective means to lay mines at enemy harbors. Rashid M. H. and Biswas D. (2018) stated that Unmanned underwater vehicles (UUV) are remotely operated Vehicle (ROV) that requires minimum intervention of human operator from a remote distance. ROVs are usually mobile, small in size & highly efficient in performing tasks with unreachable depths of the sea. These are used extensively in offshore industries due to their higher advantages over human carrying submarines. Submerged sea-mines and submarines can be identified with the UUV and secure the harbor.

Karnavas Y. L., Chasiotis I. D. and Stravoulellis D. N. (2018) stated that typical DPVs characteristics presented in Table 2.1 retrieved from commercial manufacturers' datasheets. Generally, they were powered by two to four 12 V batteries and depending upon the configuration the latter were wired in series or in series-parallel. Smaller DPVs average 0.6 meters in length, and the larger ones could up to three times longer. Range capability varied by model but generally run from one to five miles, depending also on the current drawn by the motor which was in the range of 8 up to even 30 A with corresponding power of 100 W up to approximately 700 W. A crucial quantity is the travelling speed which varies from 2.5-6 km/h as shown in Table 2.1.

Table 2.1: Characteristics of Typical Commercial DPVs

Brand/ Model	Battery Voltage (V/Ah)	Speed (km/h)	Run Time (Min)	Current Range (A)	Input Power (W)	Overall Length (m)
Oceanic Mako	12/17	2.4-4.3	40-120	8.5-11.3	100-135	0.635
Torpedo 2000	12/32	3.6	50-80	42-42	504	0.914
Farllon MK8	24/18	4.75	60-115	10-18	240-432	1.574
AUL Drako	24/36	6.0	120 +	18-18	432	1.828
AUL Predator 2000	24/18	4.5	40-100	12-30	288-720	1.168

Reader G. T., Potter I. J. and Clavelle E. (2001) mentioned that to achieve stealth the swimmer-divers have to be initially deployed a considerable distance from the beach, harbor or anchorage to be surveyed. Even when deployed from submarines the distances involved can be ten miles or more. This is a considerable distance and unaided swimmers will arrive on site.

DPVs have some limitations similar to the Autonomous Underwater Vehicle (AUVs). Sahoo A., Dwivedy S. K. and Robi P. S. (2019) opined that AUVs have a large number of applications in hazardous underwater environments. Still, AUVs have to overcome some limitations to have large-scale adoption. Some of the key challenges are low price, underwater wireless communication, long lasting batteries, advanced manufacturing techniques, smart materials, compact on-board computers with high computational power for better decision making, onboard energy generation and its efficient use.

Diving platforms are used extensively for ocean observation also. Kadiyam J. and Mohan S. (2019) broadly classified the ocean observation platforms based on the application and operational characteristics as in-situ observations using sensors mounted on ships, buoys, moorings, coastal stations, etc., and remote sensing observations such as aircraft, radar, and satellite, etc. The in-situ measurements have progressed through ages due to the advanced observation strategies and equipment. They provide highly accurate and excellent resolution data compared to remote sensing observations. The in-situ ocean observation platforms are further broadly classified as shipboard, fixed and mobile platforms as shown in Figure 2.1.

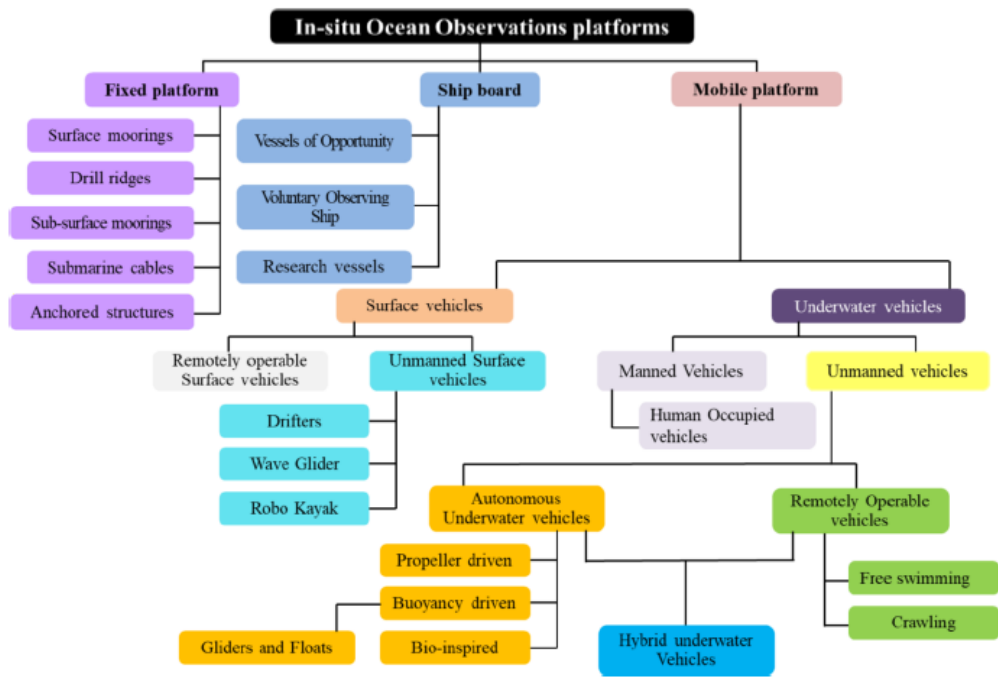


Fig 2.1: In-situ ocean observation platforms

Kadiyam J. and Mohan S. (2019) opined that the evolution of these observation platforms has laid great emphasis on improving the quality and endurance of measurements/observations, thus leading to the development of unmanned systems such as deep sea and coastal moorings mounted with sensors/instruments for continuous sampling of many ocean properties. Moored buoys are one of the most common and cost-effective means to obtain oceanographic data. But the moorings can provide data only in temporal scale, so, a vast network of moorings have to be deployed for spatial scale observations. This limitation was overcome by using mobile unmanned platforms such as remotely operable, semi-autonomous and autonomous systems for both surface and sub-surface measurements.

Li H. et al. (2021) mentioned that Diver propulsion vehicle (DPV) is a kind of small vehicle with underwater high-speed used for divers, who are able to grasp or ride on, and operate the volume switch to change the speed. The numerical simulation of DPV cruising in water is different from that of human-occupied vehicles (HOVs) and unmanned underwater vehicles (UUVs). That is, when DPV cruising, the diver's body will swing with the flow field, and its posture change will have a nonlinear disturbance to the surrounding flow field, which has a huge impact on the speed and stability of the DPV. Meanwhile, the DPV's hydrodynamic shape and propeller arrangement will also have an impact on the diver body's posture.

The National Park Service (NPS), which is a division within the US Department of Interior (DOI), is comprised of 397 units, including National Parks, Recreation Areas, Monuments and other designations. Diana L. Steller and Lisa Kerr Lobel (2012) mentioned in a review of dive 2011 statistics that a majority (70%) of the National Park Society (NPS) diving is for the purposes of natural and cultural resource management. The next greatest obligation is training and proficiency as shown in Figure 2.2.



Fig 2.2: Summary of NPS diving by purposes by percentage.

Morgansen K. A., Triplett B. I. and Klein D. J. (2007) studied that underwater locomotion has long been a subject of interest to the biological community, and the robotics and engineering communities have been inspired by the research to construct biologically derived mechanisms that mimic the behavior of individual and groups of swimming lifeforms. The motivation for this work comes from the high maneuverability, low drag, and low hydrodynamic noise that fish demonstrate over conventional propeller-driven underwater vehicles. In order to realize a transfer of aquatic biological capabilities to engineered systems, a greater understanding is needed of the interaction of submersed shape-actuated vehicles, the surrounding fluid, and effective means of controlling these vehicles.

2.2 Application

Anam H. et al. (2015) stated that a DPV generally consists of a pressure-resistant waterproof casing that contains a battery -powered electric motor, which drives the propeller. The design ensures that the propeller cannot endanger divers, diving equipment or marine life, the vehicle cannot accidentally be started or run away from divers and remain neutral buoyancy when used under water. DPVs are useful to extend the reach of divers

who otherwise is limited by the amount of breathing gas that can be done, the rate at which breathing gas is consumed under power, diver fatigue, and the time limits imposed by the dive tables to avoid decompression sickness. Common uses include cave diving and technical diving in which a vehicle is used to help move large equipment and make better use of time under water limited by the requirements imposed in diving decompression.

Karnavas Y. L., Chasiotis I. D. and Stravoulellis D. N. (2018) opined that over the years, technological advances in the scuba industry have improved a lot. More compressed air became available through the use of larger capacity tanks, better regulators were designed to make it easier to breathe at depth and computers improved dive-times management. These advances made diving more accessible to the average diver, as well as making it a more technical sport.

2.3 Brief History of DPV

Manned torpedoes, a form of diver propulsion vehicle, were employed as a concealed naval weapon during the Second World War (1939-1945). The term was popular to describe the armaments that Italy and Britain used to assault ships anchored in hostile harbors while being stationed in the Mediterranean. (Diver Propulsion Vehicle, Wikipedia, Wikimedia Foundation, 03 January 2021).

As stated in the article of Military Factory Fandom, “Human Torpedo” (2017), the Italian ‘Maiale’ was the first human torpedo (‘Pig’). It was launched close to the target while being carried by a conventional submarine. Two crew members rode on both sides of that electrically driven vessel wearing diving suits and rebreathers. They rode off the torpedo away after steering it slowly toward the target and setting the warhead's detachable warhead off like a limpet mine. The torpedo's nose contained pounds of TNT and was designed to be hung beneath a ship's keel.

Military Factory also stated that the British adopted the concept after learning how effective it could be after three Italian units successfully entered the harbor of Alexandria and damaged the- British battleships HMS Queen Elizabeth and HMS Valiant as well as the tanker ‘Sagona’ early in World War II. The Italian operators named their vessel ‘Maiale’ after their inventor Teseo Tesei claimed that it was making pig noises while parked on the beach. The official Italian name for their ship was ‘Siluro a Lenta Corsa’ (SLC or ‘Slow-running torpedo’). The British counterparts were known as ‘Chariots’.

CHAPTER 3 PROSPECT OF DPV IN BANGLADESH

3.1 Overview

To operationalize the project, an understanding of the following concepts is necessary:

3.2 Prospect of use of DPV in Bangladesh

The prospect of use of DPV may be mentioned as follows:

3.2.1 Military (Search and Rescue and Mine Laying)

For military search and rescue missions, DPVs could be a useful tool, particularly for the Bangladesh Army, Bangladesh Navy, and Bangladesh Coast Guard and other maritime agencies. During war time, DPV may be used covertly to lay mine on the enemy vessels and cause greater destruction of the enemy supply chain system.

Diver propulsion vehicles can be made to incorporate state-of-the-art technology into straight forward, durable, and lightweight components.

DPV may be developed with a propulsion system concept after extensive research and testing in natural settings including rivers underwater, swimming pools, and deep water.

This is how DPV may be created in collaboration with the best local assistance available in Bangladesh.

3.2.2 Civil (Search and Rescue)

DPVs may also be used extensively by Civil divers for search and rescue operations in the rivers of Bangladesh during the normal operation and during post natural calamities also.

3.2.3 Tourism (Ride)

Tourists in Bangladesh can utilize the DPV well, especially in the crystal-clear waters of the St. Martins Islands. The vehicle can be used for diving and snorkeling, which will draw much attention of the young and adventurous tourists of the St. Martins Islands.

3.2.4 Workshop Support

The likely location for purchasing raw materials and fabricating the parts of DPV with local assistance is to be determined after a survey of the local area. To process the production of structures step by step, few workshops - are to be selected based on the availability of particular machine sets. Other facilities at Dholai Khal will also be explored if needed.

3.2.6 Skilled Workers

The unique skill set needed to process the materials for accuracy and finishing touch is another crucial factor before choosing those workshops. For various procedures, such as drilling, lathe operation, grinding, dynamic balancing of the propeller blade and outer shell, water sealing, shaft alignment of the DPV and other relevant tasks skilled workers will be required for better performance.

3.2.7 Test and Trial Facility

Upon completion of the project, availability of the Test and Trial facility is of paramount importance. Depth of the water pond or swimming pool is also a factor for testing of the DPV. The swimming pools of defense installation and suitable Civil ponds will be considered as a ground for testing the DPV once developed.

CHAPTER 4 METHODOLOGY

4.1 Overview

Methodology is one of the most important aspects for any design and development of any project. To undertake the concept of design and development of a DPV, the methodology is considered very meticulously in order to make the project a successful one. Therefore, the methodology will be discussed in this chapter.

4.1.1 Initial Concept Design of DPV

The design of a DPV comprises of a pressure-resistant, watertight chamber where a battery-operated electric motor drives the propeller. The operation of the Diver Propulsion Vehicle will be carried out by the operator riding on the DPV. The rpm of the propeller will be controlled using the throttle. The power of the DPV will be supplied from the batteries stored inside the DPV. The diver, the diving apparatus, or marine life remains safe from the rotating propeller as it is ducted and fenced as per the design. The vehicle cannot be unintentionally started or driven away from the operator. It maintains a roughly neutral or negligibly negative buoyancy while submerged.

4.1.2 Model Design Validation

The DPV is designed using CAD generation software 'SolidWorks' having the required components installed on the DPV and the design is validated by carrying out CFD analysis by using 'Ansys Software' to estimate the force and torque generated by the propeller, velocity, and pressure distribution over the Diver Propulsion Vehicle. Various parameters will be examined, and the performance of the vehicle will be ascertained for effective use by the divers.

4.1.3. Design Finalization

Based on the result of the CFD analysis and the effective use of the vehicle, the design will be finalized for further fabrication of the DPV. Moreover, the materials will be searched in the local market and will be collected for further fabrication of the Diver Propulsion Vehicle.

4.2 Fabrication

Fabrication of the DPV body, selection of the propeller and handle will be taken in hand in a workshop having suitable machinery and skilled workers by using suitable material collected from local market. The material of the body of the DPV will be selected in such a manner so that the body anti-corrosive and lasts long and the fabrication becomes easier. Electrical items as Battery, Battery charger, Controller and Switches will be procured from local market and necessary connection will be given as per circuit diagram.

4.3 Assembly

On completion of fabrication and selection of individual component, body of the Diver Propulsion Vehicle together with motor and propeller will be assembled first. Then the electrical components such as Controller, Battery, battery charger and switch will be connected with motor and the throttle. Special precautions will be taken to connect controller with throttle making the DPV watertight. Before securing the head of the DPV body, the switch is to be kept 'ON'. The operational condition will be checked by running the propeller using throttle. If the propeller operates, then DPV will be ready for further Test-Trial at swimming pool or river.

4.4 Test-Trial

Various Test-Trial of the DPV will be carried out at a suitable Swimming pool or Pond to evaluate the performance of the DPV and Test data will be recorded.

4.5 Evaluation of Performance

Test data will be recorded during trial. Recorded Test data will be evaluated for effective use of the DPV by the divers. Future modification will be recommended as required.

4.6 Cautions

All the electric components are sensitive to water. Therefore, all the electric components except throttle will be housed inside the watertight body of DPV. Proper sealing will be done to prevent damage of the electrical components due to short circuit. The generation of heat inside the battery will be considered and will be taken due care. Moreover, charging of batteries at the fullest will be done prior each operation to ensure proper utilization of the vehicle during search and rescue operations. If not in use, the switch is to kept in 'OFF' position to avoid any incident/accident.

CHAPTER 5 DESIGN CONSIDERATION

5.1 Buoyancy Control

The tendency for an object (or diver) to float in the water is known as buoyancy. All things submerged in a fluid are affected by the force that acts in the opposite direction of gravity. When an object is submerged in a liquid or gas, the object's weight exerts downward pressure on the fluid, acting against gravity, while an upward buoyant force exerts upward pressure on the object.

In general, the following equation can be used to compute this buoyancy force:

$$F_b = V_s \times D \times g \quad (1)$$

Where, F_b is the object's buoyancy force, V_s is its submerged volume, D is the fluid's density the object is submerged in, and g is the acceleration due to gravity.

5.2 Hydrostatics

Fundamental to hydraulics, hydrostatics deals with the design of machinery for handling, storing, and utilizing fluids. Several daily occurrences, such as why atmospheric pressure varies with altitude, why wood and oil float on water, and why the surface of still water is always level, have physical answers thanks to hydrostatics. The hydrostatics concept is used in this DPV project.

5.3 Hydrodynamics and Bernoulli Equation

One area of study that examines fluid dynamics, particularly the forces acting on an item in a fluid flow, is hydrodynamics. Counting a variety of flow parameters, including speed, pressure, duration, temperature as a function of space and time is necessary to solve hydrodynamics problems in general. It will be feasible to determine or approximate the forces and moments acting on the body discovered in the stream by looking at the existing flow patterns. The Bernoulli equation comes in two basic versions, to put it simply. In the first, a compressed fluid is compared to an uncompressed flow (Anam H. et al., 2015).

Assuming the flow is steady, and there is no friction, the fluid equation applies to incompressible flow.

The Bernoulli equation can be written as follows:

$$P_1 + \rho gh_1 + \frac{1}{2} \rho V_1^2 = P_2 + \rho gh_2 + \frac{1}{2} \rho V_2^2$$

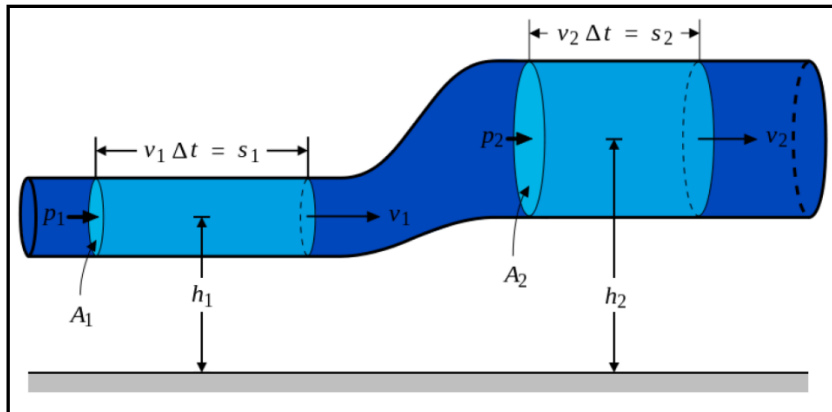


Fig 5.1: Diagram of the Bernoulli's law

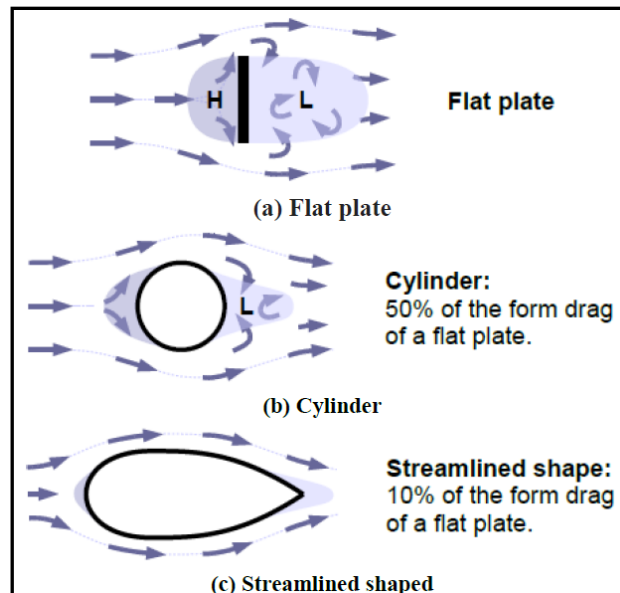


Fig 5.2: Form Drag Pressure

5.4 Drag

The force that prevents a solid object from moving through a fluid is known as drag in the field of fluid dynamics. It is also referred to as fluid resistance or drag (liquid or gas). Drag is made up of two forces: friction force, which acts parallel to the object's surface; and pressure force, which acts perpendicular to the object's surface. Drag is the portion of the resulting fluid dynamic force that acts in the direction of the movement of the body for a solid object traveling through a fluid. Lift is the component that is parallel to the direction of bodily movement (Anam H. et al., 2015). The effects of drag on a flat plate, a cylinder, and a streamlined shape are shown in Figure 5.2, where the difference in the flow is evident.

5.5 Ducted Propeller

The Popular Mechanics Magazine (Windsor H., 1937) reports on the testing of a nozzle around a boat propeller known as a Kort Nozzle, which shows that the nozzle may be expected to significantly increase the effective thrust at speeds under 4 miles per hour, resulting in quicker acceleration. In the case of propellers that are severely laden, Luigi Stipa in 1931 and Ludwig Kort in 1934 both showed that an increase in propulsive efficiency might be gained by enclosing the propeller with a foil-shaped shroud.

A marine propeller with a non-rotating nozzle is referred to as a ducted propeller, also known as a Kort nozzle. It is utilized to increase the propeller's efficiency and is particularly useful for propellers that are severely laden or have a small diameter. A shrouded propeller assembly for naval propulsion is called a Kort nozzle. In some circumstances, the shroud may provide hydrodynamic advantages over bare propellers. Benefits include improved course stability, enhanced efficiency at lower speeds (less than 10 Kts), and reduced sensitivity to debris.

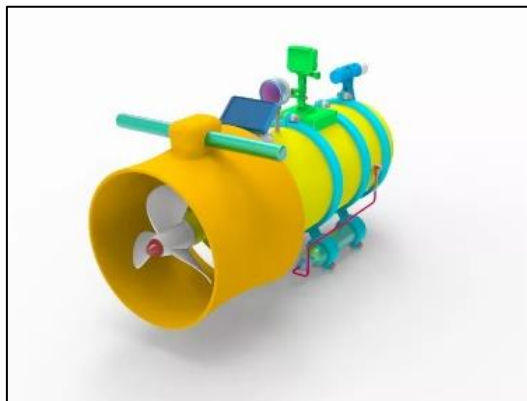


Fig 5.3: Ducted Propeller or Kort Nozzle

5.6 Base Drag

The pressure drag is significantly influenced by the body's form. The vortex area is drastically reduced along with the rear-end suction and the resistance to motion if the body's streamlined form is such that the boundary layers adhere to a converging rear end. If the body were teardrop-shaped, the body's contour would allow a boundary layer to extend far enough toward the tail before flow separation occurred. As a result, there won't be as much of an area vulnerable to vortex whirl and negative pressure.

The design of a teardrop body with an extended tapering rear end is impracticable, but if the tail is removed (bobtailed) at the location where the airflow diverges from the body's contour, the vortex (negative pressure) is the same as if the tail were allowed to converge. The term 'base area' refers to the cut-off cross-section region where flow separation would take place, and the term 'base drag' describes the resulting negative vortex pressure.

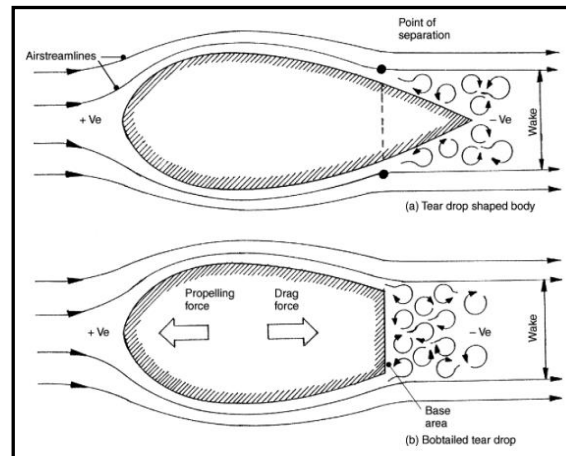


Fig 5.4: Effect of Base Drag

5.7 Computational Fluid Dynamics (CFD)

CFD has a significant impact on the evaluation of model tests as well as ship design. Many factors are having an impact on ship model basins. The goal of ship model tests is changing from evaluation to validation as CFD applications grow. Moreover, computer-based systematic series investigations are replacing experiment-based ones. The type of model testing that the designer is obliged to conduct is narrowing and, when carried out, includes increasingly precise measurements. To confirm CFD results, intensive flow measurement tests are also carried out these days. A further definition of CFD is the examination of the system as a problem of fluid flow, heat transfer, and other related phenomena using computer simulation.

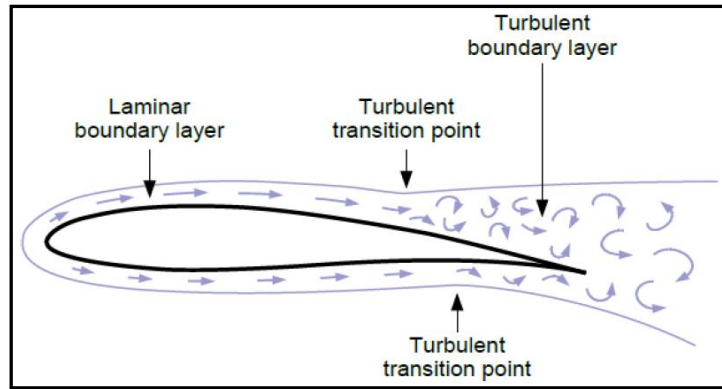


Fig 5.5: Boundary layer around an Aerofoil

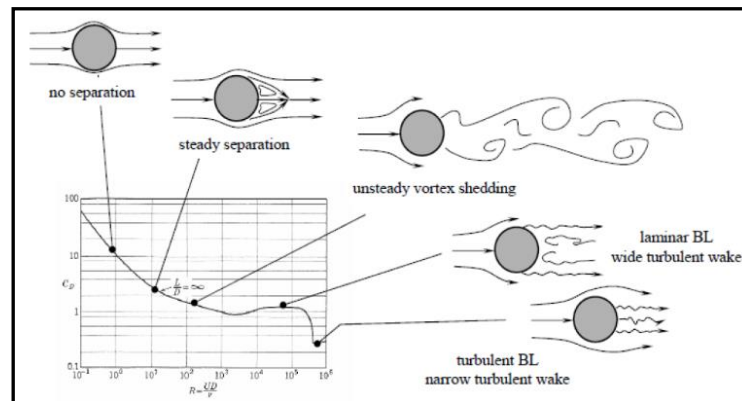


Fig 5.6: Drag on a Smooth Circular Cylinder

5.8 Sealing

Through sealing, fluid leakage into and out of the environment is kept to a minimum while also minimizing wear on the sealing faces. For the project, rotary seals, which are utilized in parts with oscillating or rotating parts to keep lubrication fluids in while preventing entry of dirt and water, provide the best sealing. Long-term performance and component longevity are both enhanced. Poly Tetra Fluoro Ethylene (PTFE) rotary seals with double-acting O-ring energization, rubber V-rings, mechanical face seals, radial oil seals, rotary shaft seals, radial and axial lip seals, and many more are examples of rotary seals.

Beyond fluid sealing, gearboxes, hydraulic pumps, axles, power steering columns, speed reducers, and transmissions, special seals like the radial oil seal and radial shaft seal have a wide range of applications. Between rotating and stationary components, or two components moving relative to one another, are radial shaft seals. They come in two main sections. One is an interference-fit cylindrical outer covering those seals statically against the housing bore. The second, a sealing lip, seals against the shaft both dynamically and

statically. Its sealing edge applies a specified radial load as it presses on the shaft's counter-facing surface.

5.9 Reduction Gear

A reduction gear is a device that allows for a reduced output speed to be required while maintaining or increasing output torque. It is a fundamental necessity of a vessel that the motor runs at a reasonably high range of rpm to have great efficiency. Yet, a propeller must run at a relatively low rpm range to function well. Due to this, a reduction gear is employed, which slows down the motor's high-speed action to the low rpm range needed by the propeller. Single reduction gears and double reduction gears are the two primary categories of reduction gears. One pair of gears makes up a single reduction gear configuration. This kind of equipment was utilized in this project.

5.10 Design Parameters of DPV

An ideal DPV is designed using SolidWorks (Version 2022) with the following components shown in Table 5.1 and illustrated in Figure 5.7.

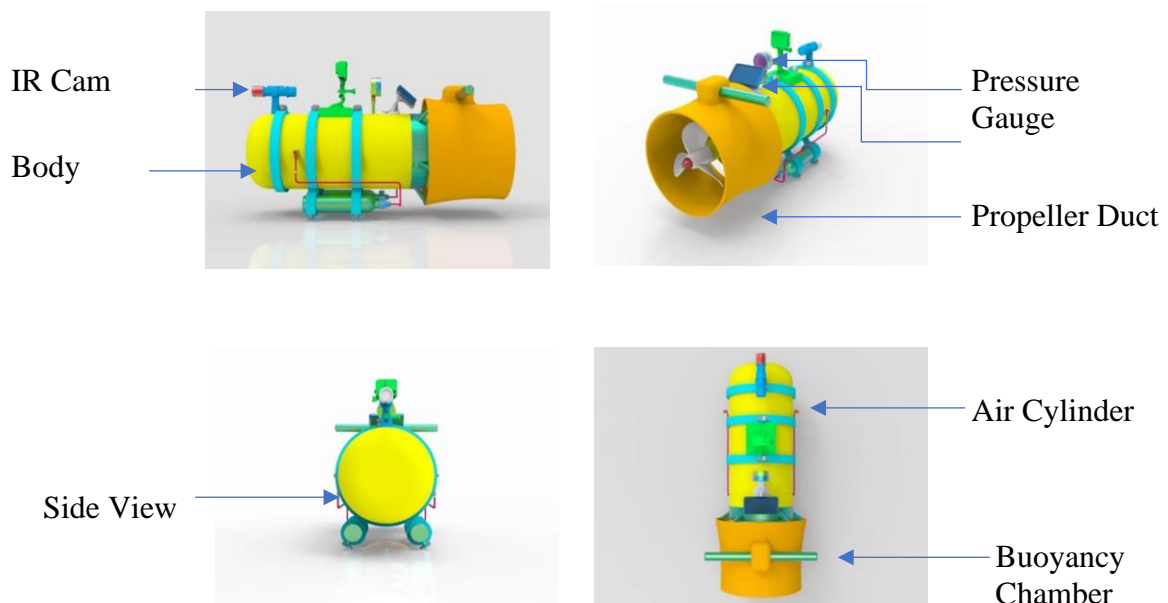


Fig 5.7: Components of DPV

Table 5.1 : Components of Initial Concept Design of DPV

Serial No.	Components	Deno	Remarks
1.	Body	01	Including Buoyancy Chamber
2.	Ducted Propeller	01	
3.	Motor	01	Housed inside the body
4.	Battery	02	Housed inside the body
5.	Compressed Air Cylinder	02	Optional item
6.	Search Light	01	Optional item
7.	IR Camera	01	Optional item
8.	Monitor	01	Optional item
9.	Pressure Gauge	01	Optional item

Initially the DPV was planned to be constructed with a buoyancy chamber which will be filled by water in order to submerge the vehicle below the water surface and to compressed air cylinders are used to release water out of the buoyancy chamber to take the vehicle at the water surface again. Later on, for ease of manufacturing, buoyancy chamber and compressed air cylinders were removed from the component list.

5.11 Project Implementation Plan

The project is planned out in several stages to ensure its successful completion. Each stage is finished before the subsequent one is started. The following Figure 5.8 shows how the project implementation plan was formulated as done.

**Literature Review ----- Design by Solid Works ----- Design Validation by Ansys ---
 Design Finalization ----- Market Survey ----- Raw Material Collection -----
 Fabrication ----- Assembly ----- Test & Trial ----- Evaluation of Performance**

Fig 5.8: Project Implementatin Plan

CHAPTER 6 DESIGN VALIDATION

6.1 Overview

The initial design needs to be validated in order to bring the design into reality. The design work done in SolidWorks is validated using Ansys software (Version 2020R2). The following paragraph will explain various aspects of design validation of the DPV.

6.2 Computational Fluid Dynamics (CFD) Evaluation

Three cases have been considered to run CFD simulation as in Table 6.1. In actual test the propeller ran at 360 rpm. In the CFD analysis cases the same rotation speed has been considered along with a much higher rotation of 1500 rpm to get a conception about the thrust, drag, and flow field that would be generated.

Table 6.1: Case studies

Aspect	Case 1	Case 2	Case 3
Geometry	Only propeller inside domain	Vehicle with tanks, without electrical components	Hydro-static Pressure (vehicle operating under 20ft)
Mesh Elements	1.3 million	2.5 million	5 million
Rotating Body	Propeller	Propeller	Propeller
Prop Rotation	360 rpm, 1500 rpm	360 rpm, 1500 rpm	360 rpm, 1500 rpm

Cross-matching the design calculations, a 3D model is generated using SolidWorks. The fabrication gets a lot easier if a CAD model is apprehended before going for manufacture. Furthermore, CFD simulation is carried out using Ansys software package.

6.2.1. Design tools and aspects

Design tools and aspects are presented in Table 6.2 below.

Table 6.2: Simulation design methods

Aspect	Designation
CAD Generation software	SolidWorks
Mesh Generation software	Ansys Mesher
Numerical Solver software	Ansys Fluent
Discretization Scheme	FVM
Relation between pressure field and velocity field	Coupled

6.2.2 Mesh properties

The 3D model that is being used to visualize then imported to the Ansys modelers and the geometry is simplified and cleaned as necessary inside to catch a good quality mesh which is a must to get solution convergence.

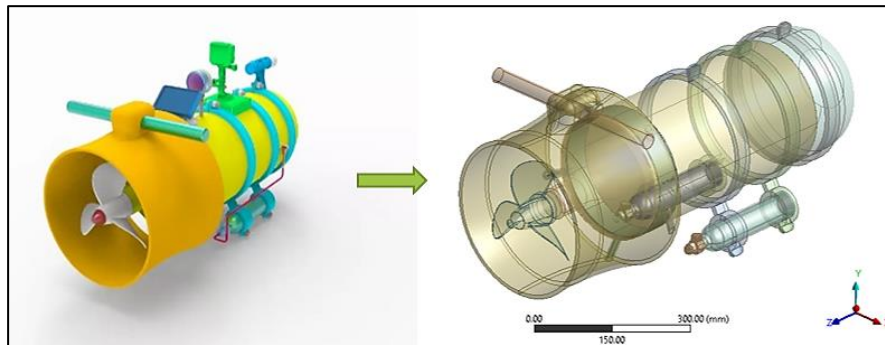


Fig 6.1. Geometry Simplification

The computational grid or mesh properties are given in Table 6.3 and Figure 6.1 shows the meshed geometry.

After the simplification flow domain is created by Boolean operation in the Ansys Design modeler CAD tool as shown in Figure 6.2. The diameter of the domain is 700 cm which is large enough to capture the flow field around the vehicle. The distance of flow inlet is 300 cm and the distance of flow outlet is kept 500 cm keeping in mind that reverse flow is not significant from the pressure outlet.

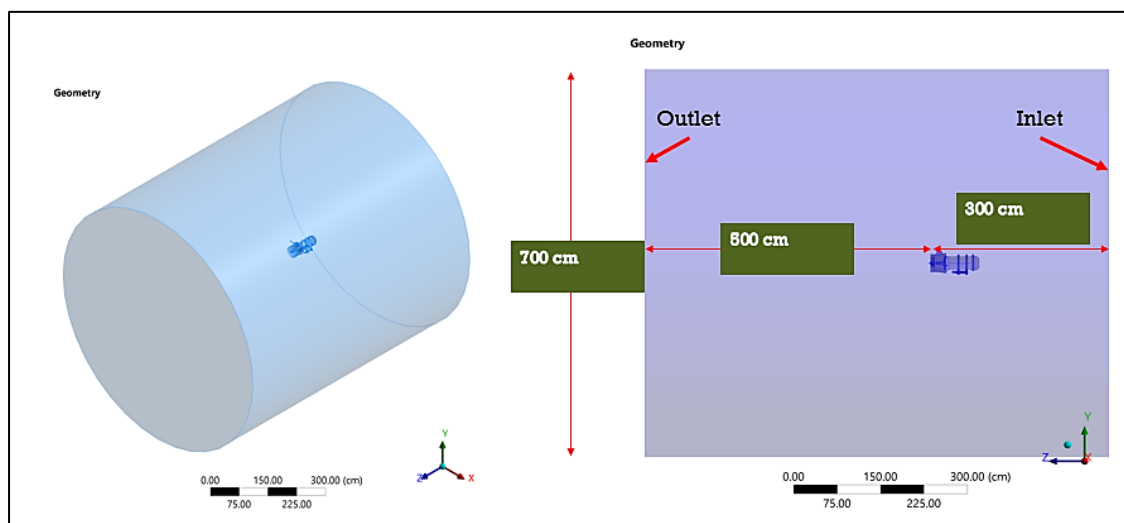


Fig 6.2. Flow Domain

Mesh: Local mesh control is applied to get fine mesh around the vehicle and coarse mesh far away from the vehicle. The computational grid or mesh properties are given in Table 6.3 and Figure 6.1 shows the meshed geometry.

Table 6.3: Mesh properties

Type	Case 1	Case 2	Case 3
Physics Preference	CFD	CFD	CFD
Solver Preference	Fluent	Fluent	Fluent
Adaptive Sizing	No	No	No
Mesh type	Unstructured	Unstructured	Unstructured
Element type	Tetrahedral	Tetrahedral	Tetrahedral
No of Elements	1300000	2500000	5000000
Skewness	Max = 0.7, Avg = 0.2	Max = 0.75, Avg = 0.3	Max = 0.75, Avg = 0.2
Orthogonal Quality	Min = 8.5e-001, Avg = 0.7	Min = 3e-002, Avg = 0.5	Min = 2.9e-002, Avg = 0.5
Aspect Ratio	Min = 1.025, Max = 925.4	Min = 10.5, Max = 615.4	Min = 10, Max = 700.5

6.2.3 Solver Setup

Then the physics solver or Ansys Fluent is set for material, domain zones, boundary conditions, viscous models, solution methods, etc. accordingly. Table 6.4 shows the solver setups.

Table 6.4: Fluent-physics

Solver	<ul style="list-style-type: none"> • Type: Pressure-Based • Velocity Formulation: Absolute • Time: Steady
Viscous Model	<ul style="list-style-type: none"> • Spalart-Allmaras (1 equation) <ul style="list-style-type: none"> - Strain/Vorticity-Based ✓ Curvature Correction
Material	<ul style="list-style-type: none"> • Water <ul style="list-style-type: none"> - Density: 1000 kg/m³ - Viscosity: 0.001003 kg/m-s
Boundary Conditions	<ul style="list-style-type: none"> • Inlet: Velocity Inlet <ul style="list-style-type: none"> - Velocity: 2.37 knots, 9.87 knots • Outlet: Pressure outlet • Propeller: Wall • DPV Body: Wall • Side faces: Wall
Reference Values	<ul style="list-style-type: none"> • Area: 0.0415 m²

Solution Methods

- Scheme: Coupled
- Spatial Discretization
 - Gradient: Least squares cell based
 - Pressure: Second order
 - Momentum: First order upwind
 - Modified Turbulent Viscosity: First order upwind

Solution Controls

- Flow Courant Number: 100

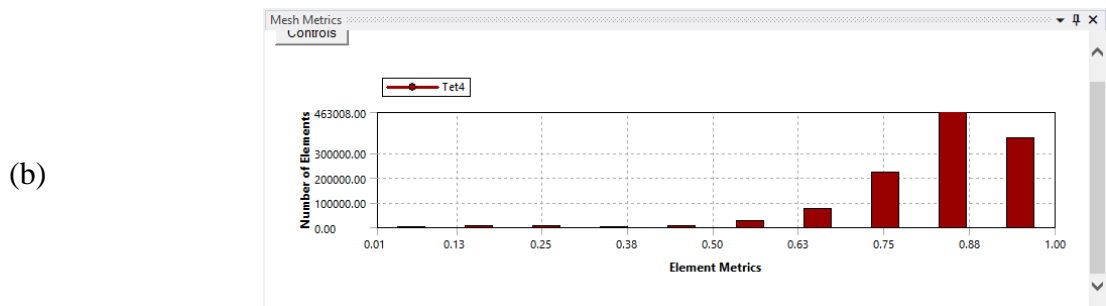
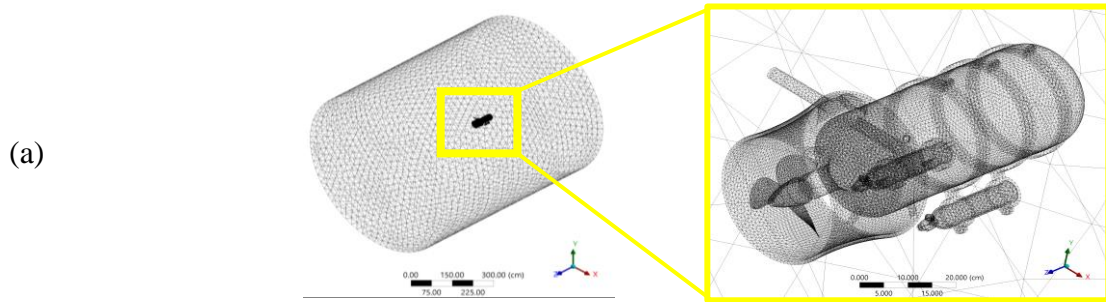


Fig 6.3: (a) Mesh and (b) Element quality

6.2.4 Material Assignment

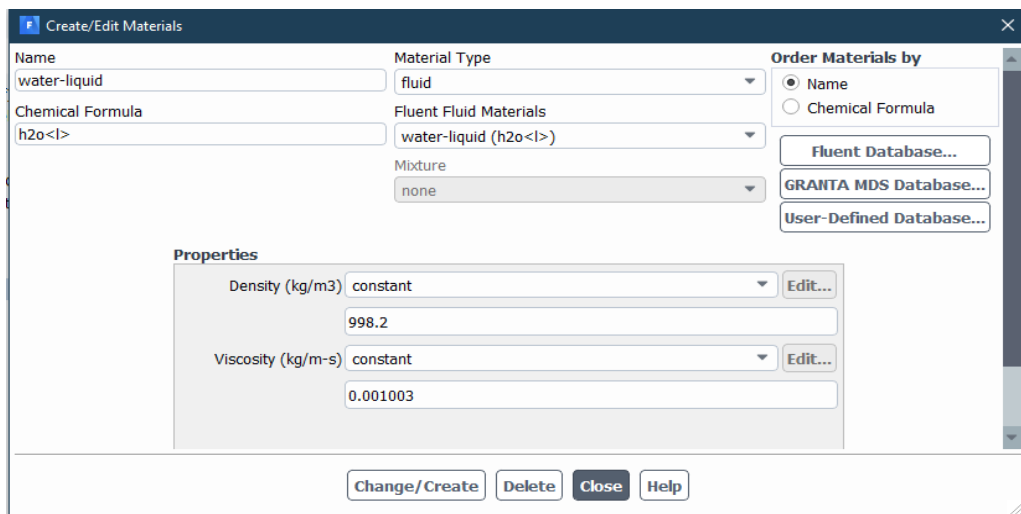


Fig 6.4: Material Assignment

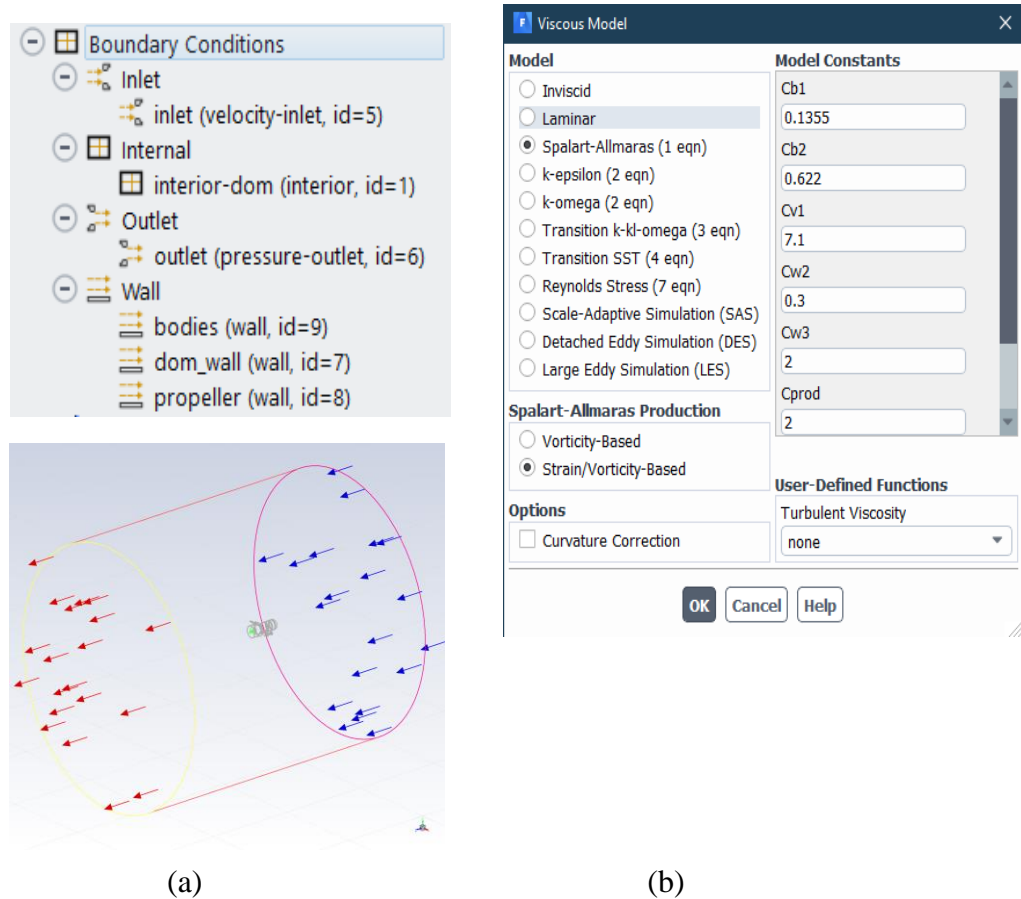


Fig 6.5: (a) Boundary Conditions and (b) Viscous Model

6.2.5 CFD Results

The continuity and momentum equations for compressible fluid or water are solved and converged up to 10^{-5} residuals. From Table 6.5, it can be seen the thrust generated by the propeller is 3.18 N for case 1. Whereas the thrust generated by the propeller is 2.91 N for case 2 because of the drag generated by the vehicle body.

Table 6.5: CFD Results

	Case 1		Case 2		Case 3	
	360 rpm	1500 rpm	360 rpm	1500 rpm	360 rpm	1500 rpm
Force generated by the Propeller	3.18 N	5.19 N	2.91 N	5.13 N	2.91 N	5.13 N
Resistive Torque by the Propeller	0.15 N-m	0.27 N-m	0.057 N-m	0.2 N-m	0.057 N-m	0.2 N-m
Induced velocity by propeller	0.68 m/s	0.73 m/s	0.72 m/s	0.73 m/s	0.72 m/s	0.73 m/s

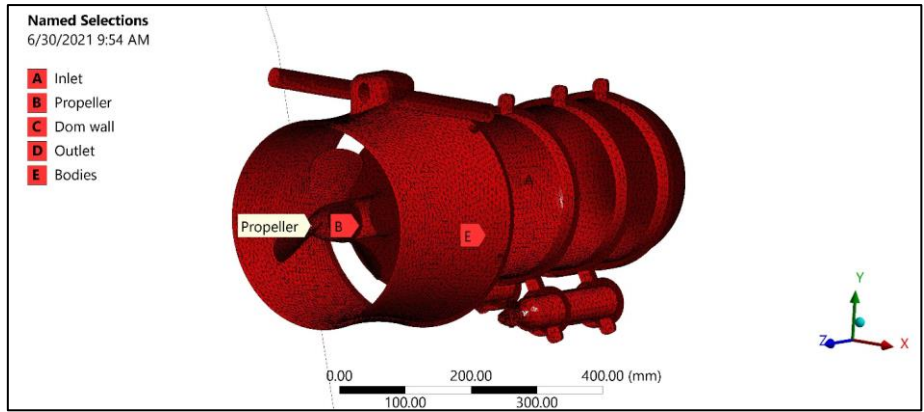


Fig 6.6: Simplified Geometry and Mesh (case-2)

From Figure 6.6 to Figure 6.12 shows the pressure contour, velocity streamlines for the cases.

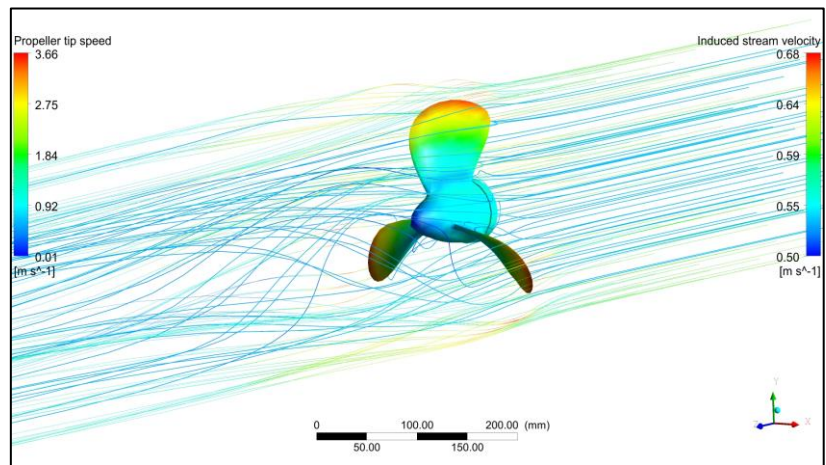


Fig 6.7: Propeller tip speed and induced streamline velocity at case-1-360 rpm

From Figure 6.8, it is seen that maximum of 180 Pa pressure is exerted on the blades, which indicates no possible stress-strain failure or permanent bending due to high stress.

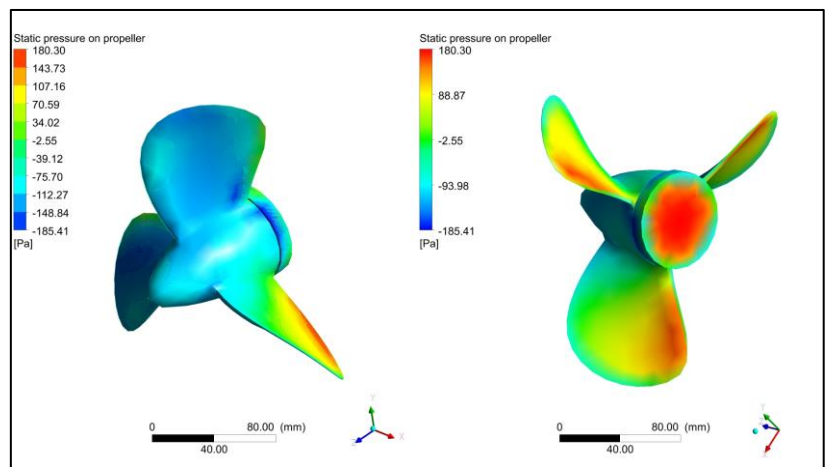


Fig 6.8: Static pressure contour on propeller at case-1-360 rpm

The maximum static pressure is 772 Pa on the blunt nose which creates a major drag on the vehicle. However, a conical nose implementation might reduce the drag significantly and will give the vehicle more maneuver capabilities.

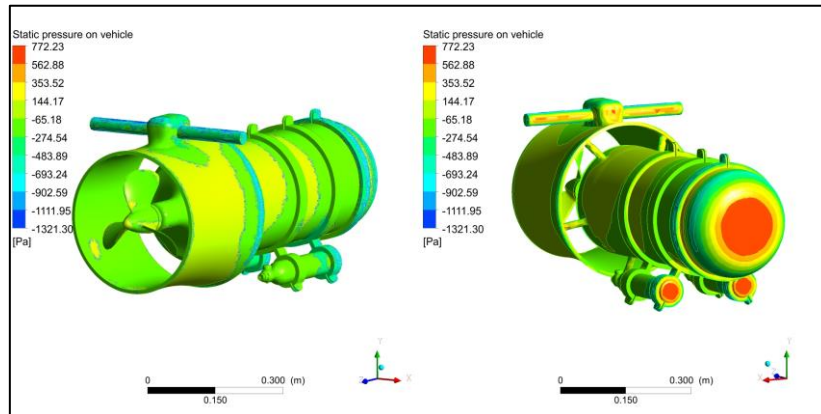


Fig 6.9: Static pressure on the vehicle at case-2-360rpm

Figure 6.9 shows that maximum of 173 Pa pressure is exerted on the blades when the propeller rotates at 360 rpm and the vehicle moves forward.

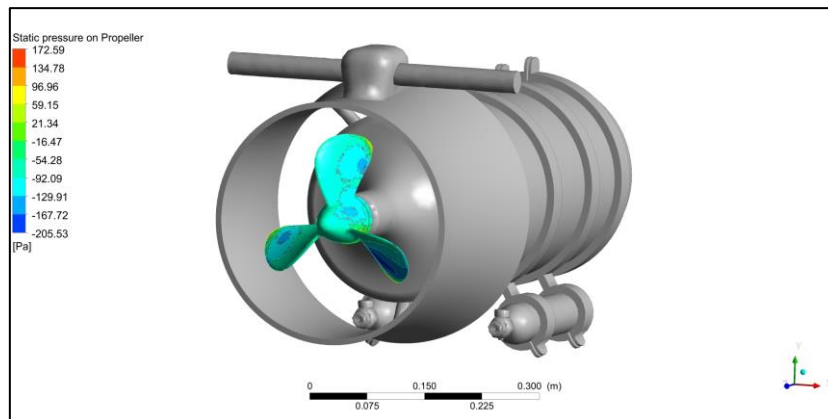


Fig 6.10: Static pressure on the propeller at case-2-360 rpm

The flow streamlines around the vehicle induced by the rotating propeller is visualized in Figure 6.10. The Kort nozzle works fine as it should but the continuous flow gets disturbed after the cylindrical part and makes a pocket where water is swirling just before the propeller intake which is greatly reducing propeller efficiency. More oblique shape at the end of the cylindrical body might result uninterrupted flow.

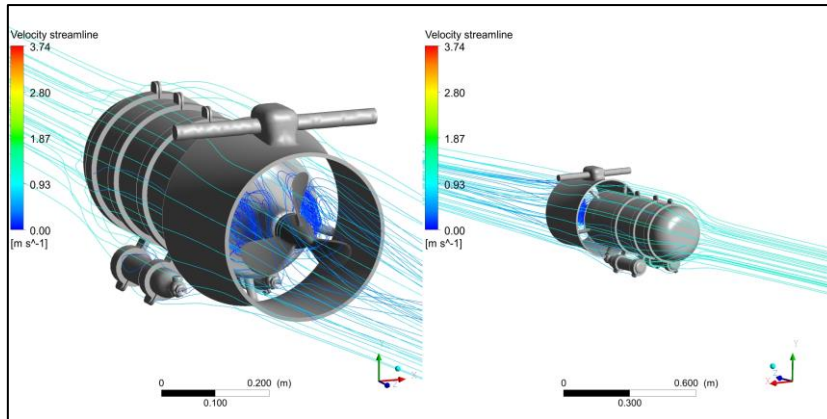


Fig 6.11: Velocity streamlines around the vehicle at case-2-360 rpm

Figure 6.12 and 6.13 show that when the vehicle is under the water at 20 ft depth the absolute pressure on the vehicle would be between 58329-60058 Pascals. Experiments show that the vehicle can sustain this amount of pressure without any leakage.

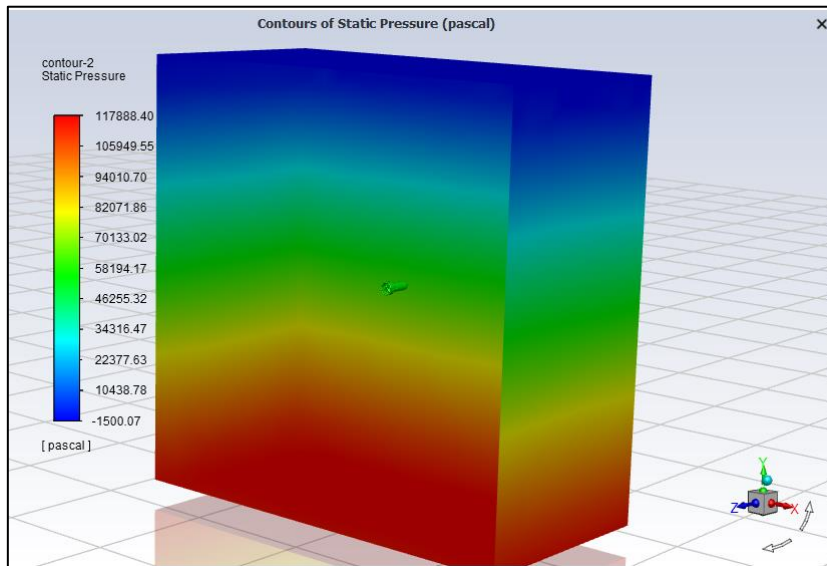


Fig 6.12: Pressure contour of the domain when the vehicle is operating at 20ft depth (Case-3-360 rpm)

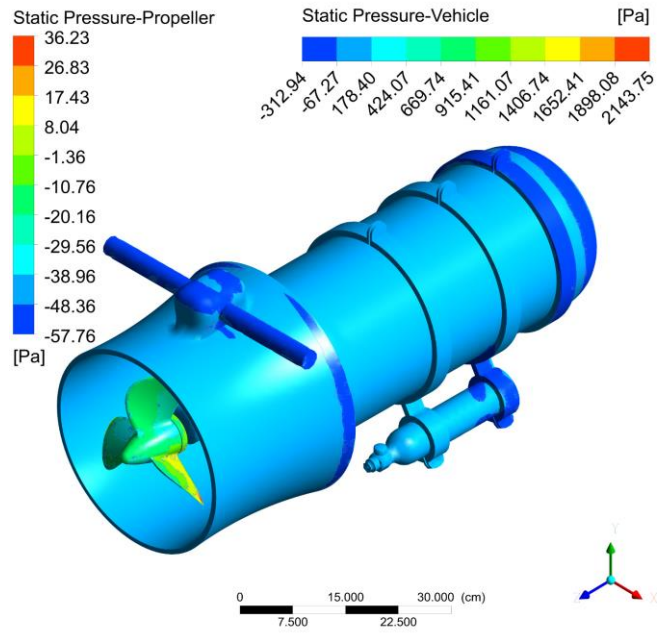


Fig 6.13: Pressure contour on the vehicle sunk at 20ft depth (case-3-360 rpm)

CHAPTER 7 FABRICATION OF BODY AND PROPELLER OF DPV

7.1 Overview

This DPV has a compact, powerful, hydrodynamically efficient design. Due to ease of modification and less maintenance, Nylon is chosen as a body. A lightweight propeller made of aluminum chosen for even mass distribution and simple balancing. The propeller efficiency was increased by using a ducted propeller.

7.2 Fabrication Machinery

Various equipment was used for different jobs during the fabrication of the DPV. Table 7.1 shows a list of equipment with basic purposes as mentioned below:

Table 7.1: Fabrication Machineries

Ser	Description	Basic Purpose
1	Lathe Machine	Hull Making
2	Drilling cum Tapping m/c	Hull drilling & tapping
3	Surface Grinder	Machining rudder blade
4	Hydraulic Press	Shaft insuring and pressure testing
5	Portable TIG Welding Machine	Propeller Guard Making
6	Power Hacksaw	Cutting Nylon shaft for hull making

7.3 Fabrication of Body

The solid nylon bar (Dia-300mm and Length- 5ft) was customized in the workshop to make it a hollow body of DPV as shown in Figure 7.1. Internal and external threads were cut to make it watertight as shown in Figure 7.2.

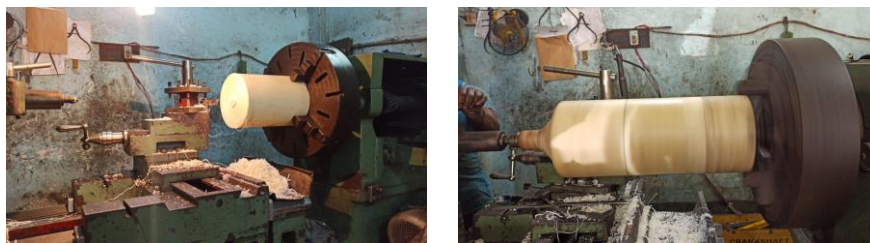


Fig 7.1: Construction of body of Diver Propulsion Vehicle.



Fig 7.2: External Threading around the body of Diver Propulsion Vehicle.

7.4 Selection of Propeller

A suitable three blade propeller made of aluminium of Dia 228.6 mm (9 inch) was collected from local market to use in the DPV.

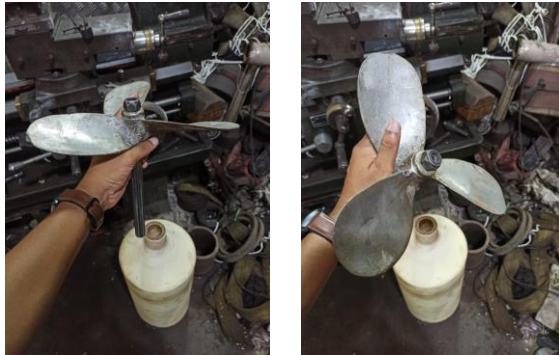


Fig 7.3: Selection of the propeller of Diver Propulsion Vehicle.

7.5 Assembly of Body and Propeller

The body and the propeller was assembled together on completion of fabrication of DPV.



Fig 7.4: Assembly of body and propeller of Diver Propulsion Vehicle.

CHAPTER 8 DESIGN OF ELCECTRICAL SYSTEM OF DPV

8.1 Overview

The design of electrical system is very important as the propeller of DPV is rotated by the motor which is run by battery where both motor, battery, controller are housed inside the water- tight body of DPV. The rpm of the propeller is controlled from outside by the throttle by diver.

8.2 Electrical Components

The main electrical components of the DPV are selected as listed in the table as follows:

Table 8.1: Electrical components of DPV

Ser	Component	Deno	Basic Purpose
1	DC Motor, rpm 3600,250 W	1	Drive the Propeller
2	24V Sealed Acid Battery, 12 Ah	2	Power to motor and controller
3	Controller	1	Control motor, throttle and switch
4	Battery Charger with port	1	Charging of battery
5	Throttle	1	Control rpm of the motor and propeller
6	Switch	1	Power to the Controller and Throttle

For small and simple maintenance, Sealed Lead Acid Battery Pack (Min 12V 12 Amps) is used.

8.3 Run Time Calculation

Run time calculation is given by following:

$$\text{Motor Power, } P = 250 \text{ W}$$

$$\text{Battery Voltage, } V = 24\text{V (Two Battery in Parallel)}$$

$$\text{Current Drawn, } I = P/V = 250/24 = 10.42 \text{ Amps}$$

$$\text{Rated Capacity} = 12 \text{ Ah}$$

$$\text{Run time} = 12/10.42 = 1.15 \text{ hours} = 70 \text{ min}$$

8.4 Electrical Component Diagram

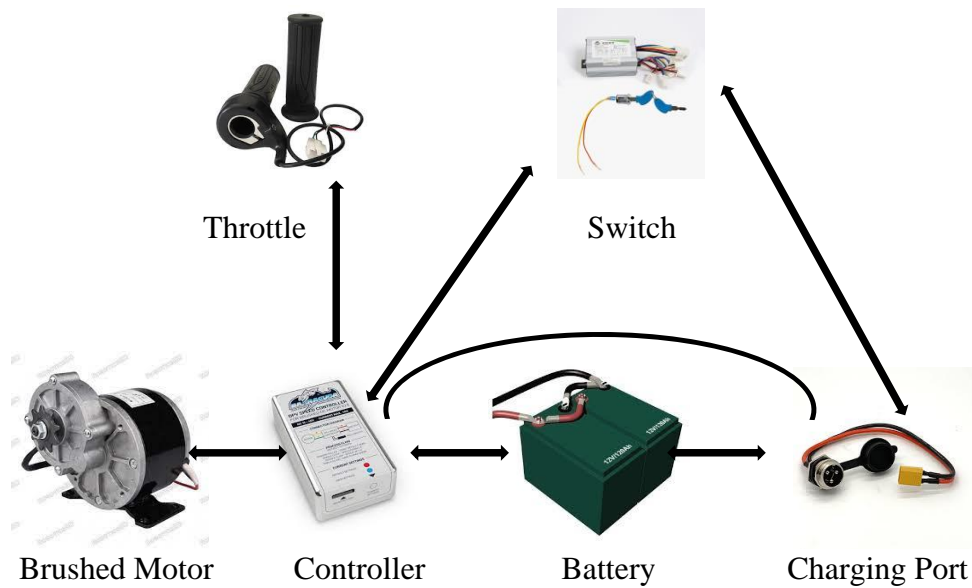


Fig 8.1: Diagram of Electrical components

8.5 Cautions

All the electric components except throttle remain inside the watertight body of DPV. Sealing is very important as water leaks inside the body will cause short circuit and damage the electrical components. The generation of heat inside the battery is another important aspect that needs to be taken care. Moreover, full charging of batteries prior operation is to be made sure to avoid any trouble of battery exhaustion during any search and rescue operations.

8.6 Assembly of Mechanical and Electrical Component

The electrical components including batteries were secured inside the hollow space of the DPV. The throttle was kept outside the body and connected with the controller by narrow passage made through the body. The passage was sealed by a special type of glue to protect any water insertion into the body of DPV. Metal guards were used on the surroundings of the ducted propeller to protect the diver during operation. The assembled mechanical and electrical components is shown in Figure 8.2.



Fig 8.2: Assembly of Mechanical and Electrical component of DPV.

8.7 Charging of DPV

Normally the battery charging port is kept inside the body of the DPV and needs to be charged before the operation by opening the forward side (head) of the body of DPV.

CHAPTER 9 EVALUATION OF PERFORMANCE

9.1 Overview

The goal of making DPV was to obtain maximum performance that will be used to dive and easy to operate. DPV Performance was tested in the DSC&SC Swimming pool and Aftab Nagar Pond, Banashree, Dhaka. The test is done to get the performance of the DPV that are in the form of speed, endurance, maneuver, and depth test.

9.2 Test Data

Various trials have been conducted and are appended in Table 9.1 and Figure 9.1.

Table 9.1: Test Data

Description	Test 1	Test 2	Test 3	Test 4
Load (kg)	63.00	71.00	71.00	75.00
Diver's Position	Horizontal	Vertical-Horizontal	Horizontal	Horizontal
Distance (m)	50.00	50.00	50.00	50.00
Time (sec)	91.00	129.00	100.00	99.00

9.2.1 Findings

Due to the position of diver during the trial, the run time varied from minimum 99 Sec to maximum 129 Sec. The position of the diver affected much on the drag and the time taken to pass the distance using the DPV. For example, during Test 3, when the diver was in horizontal position i.e. parallel to the ground, the DPV created less drag and thereby a diver of 71 kg weight could cross 50 m distance in 100 seconds. Whereas in the Test 2, the same diver when he was in a vertical-horizontal position i.e. not fully parallel to the ground and created higher drag, could cross the same distance in 129 seconds. That means, due to the increase of drag, the total time increased to cross the same distance.

MULTIPLE VALUES BY 'PHYSICAL TRIAL DATA'

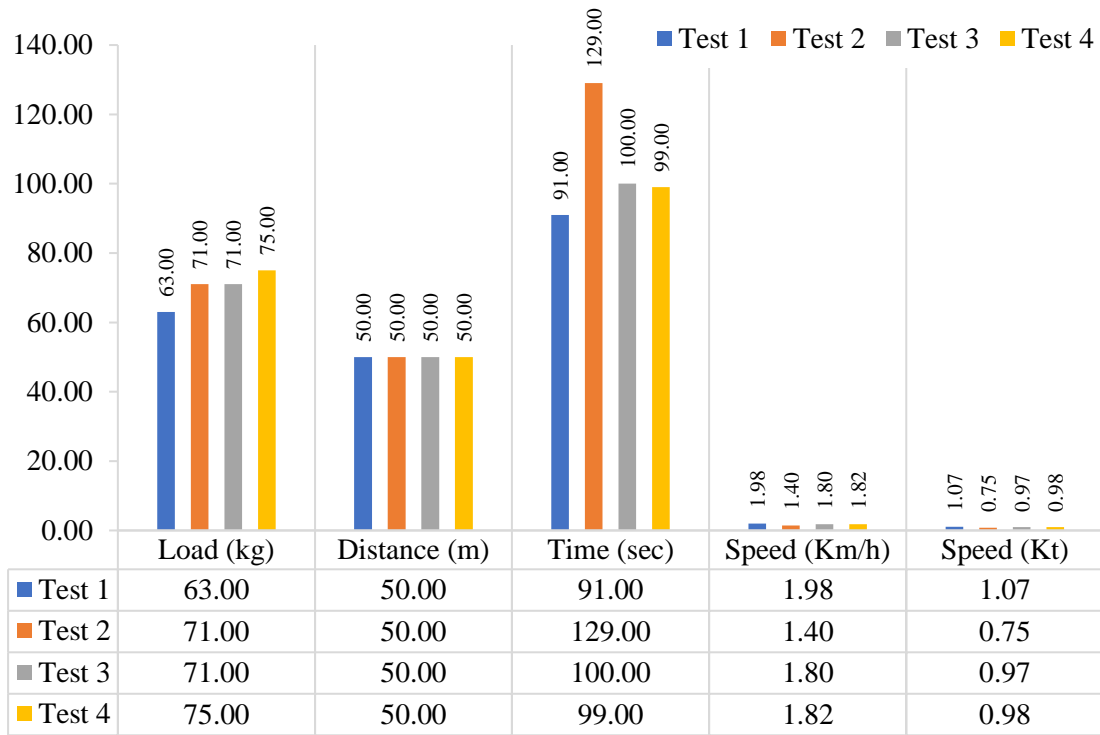


Fig 9.1: Physical Trial Data

9.2.2 Speed Testing

Speed test is to test the maximum performance obtained from DPV. For surface run the maximum speed obtained is 1.07 Kts. A digital watch was used to count the time for a fixed distance (25 m) of the swimming pool.

9.2.3 Endurance Testing

The testing is related to how long the operation of DPV can be carried out. Though the calculated runtime was 70 minutes, however in a practical test the result reaches up to 90 minutes. Added efficiency of the propeller and less drag on the surface could be the reason for the added runtime.

9.2.4 Maneuver Testing

It is the testing operation of DPV with varying angle turns, starting from 45, 90, 180, and 360 degrees. Testing with the angle is done with the handle and angle direction was given from the higher position of the water level.

9.2.5 Testing Leakage and Depth of Operation

Leakage testing and depth of allowable operation are done at a design depth of 6.1 meters (20 Feet). It aims to test the capabilities of DPV based on designed data. No leakage was found at the designed depth. Datasheet is shown in Table 9.2.

Table 9.2: Datasheet for Leak Test

Ser	Depth (m)	Leakage status
1	5	Negative
2	6.1	Negative

9.3 Performance of DPV

9.3.1 Thrust Measurement

We have, Propeller pitch, $P = 0.203 \text{ ft} = 2.44 \text{ in} = 0.062 \text{ m}$, Motor speed = 3600 rpm,

Gear Ratio = 10

$$\text{Theoretical Speed, } V_T = \frac{\text{Pitch(ft)} \times n \text{ (rpm)} \times 60}{\text{Gear Ratio} \times 1852} \quad (1)$$

$$= \frac{0.203 \times 3600 \times 60}{10 \times 1852}$$

$$= 2.37 \text{ knots} = 1.27 \text{ m/s} \quad (2)$$

As the actual speed, $V_A = 1.07 \text{ knots} = 0.6 \text{ m/s}$

$$\text{Hence, Real Slip, } S = (V_T - V_A)/V_T = (2.37 - 1.07)/2.37 = 0.55 \quad (3)$$

$$\text{Propeller speed, } n = (3600 \text{ rpm}/10)/60 = 6 \text{ rev/s} \quad (4)$$

As the propeller diameter is 9 inch, or 0.23 m, and the area, $A=0.0415 \text{ m}^2$, hence,

$$\text{Calculated Thrust, } T = \rho A P^2 n^2 S$$

$$= 1000 \times 0.0415 \times 0.00384 \times 36 \times 0.55$$

$$= 3.15 \text{ N} \quad (5)$$

From Table 6.5, CFD analysis shows a thrust of 3.18 N at propeller rotation of 360 rpm.

9.3.2 Pressure Measurement

When the vehicle operates at 20 ft or 6.1 m depth under water the static pressure is,

$$\text{Static Pressure, } P = h\rho g = 6.1 \times 1000 \times 9.81 = 59841 \text{ Pa} \quad (6)$$

Again, Figure 6.12 shows, converged solution of CFD analysis gives static pressure on DPV surface between 58329-60058 Pascal, which is the same as the calculated value.

9.3.3 Diver Propulsion Vehicle Specifications

The major specification of the diving propulsion vehicle is given in Table 9.3.

Table 9.3: Diver Propulsion Vehicle specifications

Ser	Parameter	Value
1.	Weight	30 (kg)
2.	Motor Output	250 (W)
3.	Motor RPM	3600
4.	Propeller RPM	360
5.	Maximum Speed	1.07 (approx.) (Kts)
6.	Maximum Depth	6.1 (m)
7.	Maximum Operation Time	90 (min)

9.3.4 Comparison of the New DPV with Typical Commercial DPVs

Table 9.4: Comparison of New DPV with Typical Commercial DPVs

Brand/Model	Battery Voltage (V/Ah)	Speed (km/hr)	Run Time (Min)	Current Range (A)	Input Power (W)	Overall Length (m)
Oceanic Mako	12/17	2.4-4.3	40-120	8.5-11.3	100-135	0.635
Torpedo 2000	12/32	3.6	50-80	42-42	504	0.914
Farillon MK8	24/18	4.75	60-115	10-18	240-432	1.574
AUL Drako	24/36	6.0	120 +	18-18	432	1.828
AUL Predator 2000	24/18	4.5	40-100	12-30	288-720	1.168
<u>New DPV 2023</u>	<u>24/12</u>	<u>1.98</u>	<u>60-90</u>	<u>10.42</u>	<u>250</u>	<u>0.84</u>

Though the speed of the new DPV is less than the previous DPVs, other parameters seem quite encouraging.

CHAPTER 10

CONCLUSION AND RECOMMENDATIONS

10.1 Conclusion

Diver Propulsion Vehicle (DPV) is a battery-propelled mechanical device used for extending the range and reducing fatigue of divers who move freely underwater for search and rescue operations as well as for exploration purposes. For a wide range of diving operations, sneaking, surveying, exploring, searching, and documentation, DPV offers speed and a long range to cover a large region. DPV can be utilized for underwater observation as well as fleet protection for submarines and other vessels. The nylon body of the housing is light in weight, good strength, easy to move and prevents water infiltration.

DPV can be used as a secret weapon for Bangladesh Navy, Bangladesh Coast Guard, and other maritime organizations. In the case of military application, combat divers can cover a wide distance at a reasonable speed using DPV with considerable loads. Many accessories like lights, compasses, pressure sensors, temperature sensors, and video cameras may be mounted on the DPV.

A DPV prototype was designed and fabricated for the project. Designed prototype DPV is developed using SolidWorks, and a CFD analysis was carried out using Ansys software. After that, a DPV model was fabricated using resources from the local market. This project preliminarily focused on design, fabrication of DPV and simulated various parameters to get better results. Finally, the test and trial was carried out and speed of the DPV was found to be 1.07 Kts (1.98 km/hr). The performance of the DPV were evaluated and it is found that it can be effectively used for search and rescue operations in Bangladesh. The scope of research is to improve the performance of DPV either in the form of speed, safety, endurance, and depth of operation.

10.2 Recommendations

The followings are recommended:

- a. The design may be adopted for the construction of indigenous DPV for the divers to enhance the indigenous capability of search and rescue operations of the defense forces (refer to Chapter 1, Section 1.2).
- b. Further Research and Development (R&D) may be carried out to improve its performance in case of monitoring, safety and operational capability (Sahoo et al. 2019 and refer to Chapter 8 and 9).

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