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Development of Tail and Nose Cone for Underwater Vertical Profiler Using Fused Deposition Modelling Technology

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Abstract*— Unmanned underwater vehicle (UUV) research is currently a prominent and quite well-known topic for researchers from various engineering disciplines. A wide number of applications for 3D printing technologies have been explored, including robotics, automotive components, food, healthcare, space, marine, etc. This paper introduces the implementation of additive manufacturing technology (3D printing) into marine applications. The use of various 3D printing processes to create complex, cost-effective profiles have recently gained popularity to test the durability of newly designed products. The subsequent sections will explain the development of 3D printed nose and tail cones for the Underwater vehicles which will be used for underwater exploration. The development process is divided into the design of nose and tail cones using Solidworks, a 3D design software, flow analysis for the estimation and reduction of drag, operational depth of 3D printed parts using FEA software ANSYS, and prototyping using fused deposition modelling technology. The developed tail and nose cone were implemented into the vertical profiler and tested at the NITK swimming pool and successfully profiled the vertical column of the pool.

***Index Terms*— 3D Printing, Nose Cone, Tail Cone, Underwater Vehicle.**

I. INTRODUCTION

Any member of the class of vehicles designed to operate in the underwater environment is referred to as an underwater vehicle. These are Self-propelled vehicles, which are normally launched from a surface vessel such as boat and can operate for a few hours to many days. UUVs are increasingly being used in the commercial, scientific, military, and have a wide range of demands in marine geoscience. The classification of the Underwater Vehicles is as follows, AUV- Autonomous Underwater Vehicles., ROV- remotely operated vehicles., HOV - Human Occupied Vehicle.

As discussed above these are Self-propelled vehicles deployed from the surface vessel and data can be collected from the onboard sensors. These are powered either by an onboard battery or from the surface using High-Power Tether Cables. Underwater Remotely Operated Vehicles were used to explore or investigate marine habitats that were too dangerous for humans to reach, such as deep oceans (below 100 meters down to 10 kilometers), archaeological wrecks, and hydrothermal vents. The human-occupied vehicle is a type of submersible that can take engineers, researchers, and various electronic devices and equipment to various deep-sea complex exploration, scientific investigation. AUVs can be fitted with several sensors to monitor the concentration of specific elements or compounds, light absorption or reflection, and the existence of microbial organisms. Conductivity-temperature-depth sensors (CTDs), fluorometers, and pH sensors are examples of such sensors.

3D printing, also known as additive manufacturing or rapid prototyping, is a technique for printing three-dimensional objects by depositing successive layers of material in a layer-by-layer pattern. The Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS) and Stereolithography (SLA) technologies are employed by most commercial 3D desktop printers. Researchers can quickly and cheaply produce prototype components and models using 3D printers, and they can do this from the convenience of their office. A wide number of applications for 3D printing have been investigated, including robots, automotive parts, guns, medical, space, and marine.

Additive manufacturing processes, such as those used in 3D printers, offer various advantages over traditional production methods, such as the production of complicated geometries, optimal material utilization, the elimination of costly tooling, etc. All 3D printing technologies, nevertheless, require a 3D CAD model that is exported to the slicing software as .STL (Standard Tessellation Language) file format, which includes the coordinates of the vertices of triangulated sections for each surface of the 3D model.

The following sections discuss the few commonly used technologies through which Additive Manufacturing can be achieved.

1. Photopolymerization

This method of additive manufacturing involves the selective curing of a liquid polymer through a polymerization process that is controlled by light (commonly a UV light source). The resin is photochemically solidified because photopolymers are photochemically solidified and generate a single layer of the required 3D structure when exposed to ultraviolet light.

2. Material extrusion/ Fused Deposition Modelling

It is a 3D printing process that utilizes a thermoplastic filament. This filament is deposited on the building object after being fed from the spool through a moving, heated extruder head. Thermoplastics such as polylactic acid (PLA), thermoplastic polyurethane (TPU), acrylonitrile butadiene styrene (ABS) polyethylene terephthalate glycol (PETG) are some of the filament materials extruded.

3. Powder bed fusion

It is an Additive Manufacturing technology, where the material will get melted and fused together using heat, a laser, or electron beam to make a three-dimensional object. They are Laser Fused, Electron Beam fused, Fused with agent and energy, and thermally fused. Multi Jet Fusion (MJF) is a method of creating 3D geometrical pieces in which the powder bed is heated evenly at the start and a fusing agent is utilized to connect the powder.

II. PROBLEM STATEMENT

The vertical profiler was developed for the underwater research in the vertical column of the water. And the tail cone of it made with two 3D printed parts namely, tail cone and tail cone tunnel where the thruster was mounted.

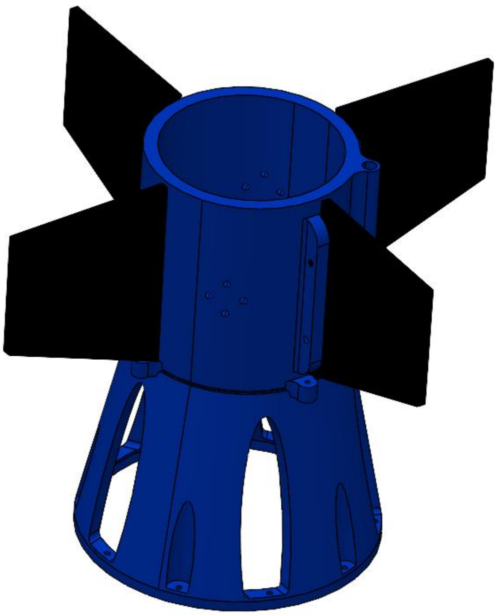

Fig 1: CAD Model of Tail cone

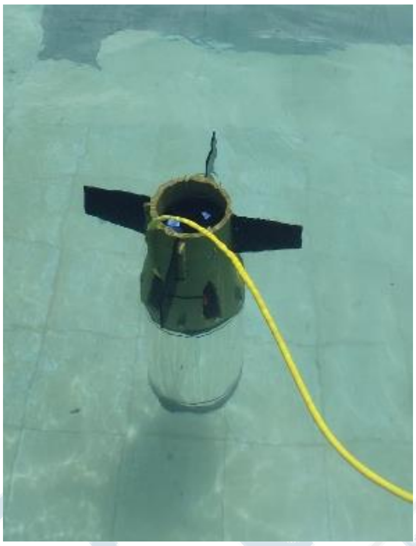

Fig 2: Testing at NITK Swimming pool

The vehicle was tested in the NITK swimming pool, and the following observations are made.

1. The thruster was producing enough thrust to drive the vehicle in the forward motion.
2. Since the water jet from the thruster was directly hitting to the aluminum plate (enclosure of hull) and moving out radially, the reverse thrust was not enough to get the vehicle to the surface.

The above problem can be solved by optimizing the geometry of the tail cone and nose cone by drastically minimizing the drag.

III. RELATED WORK

This section offers a significant amount of information regarding the design of underwater vehicle nose and tail cones as well as watertight 3D printing techniques.

[1] Shows the Optimal design of the nose and tail of an underwater vehicle hull to minimize the drag force using numerical simulation. They had taken four different geometries derived from Myring equations, tangent ogive equations, and parabolic curve equations. The results were obtained using the ANSYS Fluent software's 3D steady flow to simulate the flow. In the four geometries inspected, the ellipsoidal geometry will exhibit least drag.

[2] shows how to evaluate the functionality of an ellipsoidal head that was designed and built to enhance the hydrodynamic performance of a high-speed underwater vehicle. It has been discovered that a head with an ellipsoidal profile can improve the vehicle's hydrodynamic performance.

[4] shows us to create a watertight and airtight container. This article will give you an idea of how to set up your printer to manufacture watertight parts for underwater operation. The 3D printed part will become bulkier as more water is absorbed into it. As a result of the change in buoyancy, the vehicle will lose its stability and move along a path that is not predetermined.

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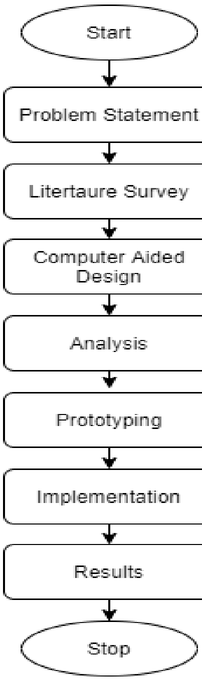
IV. METHODOLOGY:

The methodology is derived by considering the factors mentioned in the background work, and it is discussed in the subsequent sections.



Mechanical Design:

The nose and tail geometries in this study were developed using equations from [5].

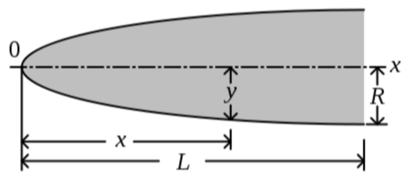
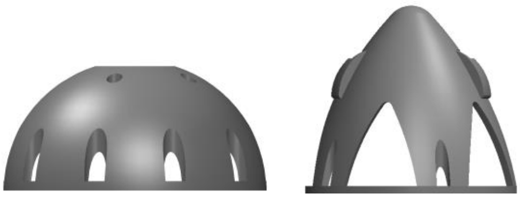


Fig 3: Dimensions used in equation

$$y = R\sqrt{1 - \frac{x^2}{L^2}} \quad (1)$$

Where L is the total length of the cone, R is the radius of the cone base, y is the radius at any point x, by using above eq (1) a two-dimensional 2D shape is obtained. A 3D geometry will be obtained by rotating it around the centerline. The corresponding models were developed in Solidworks.



(a) **(b)**

Fig 4: 3D Model of (a) Nose cone (b) Tail cone

Analysis:

The time of underwater exploration and activities is shortened, and energy consumption is increased in autonomous underwater vehicles when the drag force is increased. One of the ways to minimize the energy consumption is to optimize the shape/geometry of the vertical profiler. The developed geometries were analyzed using ANSYS fluent and the observations were discussed below.

Boundary Conditions used here are:

Flow analyzed: Steady flow

Flow speed from the thruster on a tail cone: 5m/s

Speed of the vehicle: 1m/s

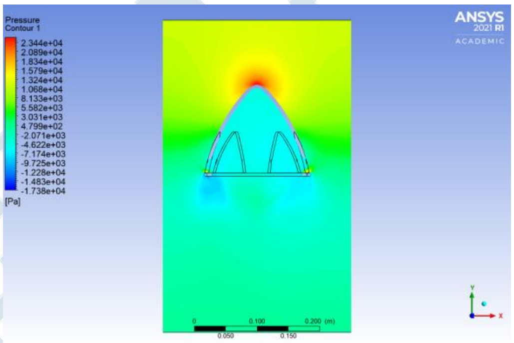


Fig 5: Pressure at Tail cone

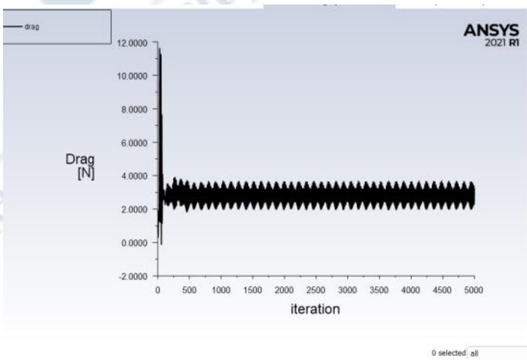


Fig 6: Drag at Tail cone

Upon applying boundary conditions, it is observed that the tail cone geometry will have a drag force of 2.8N which is negligible by considering the force exerting on the vehicle i.e., 49N.

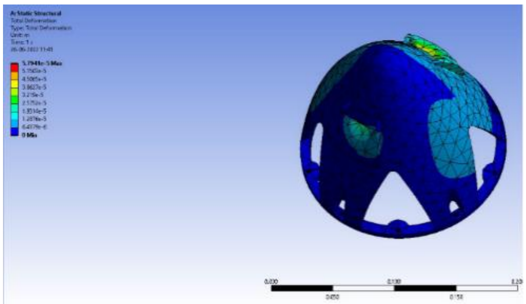


Fig 7: Deformation at 10m.

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The geometry is further analyzed for the deformation/failure at multiple depths of underwater column from 2m to 10m. The deformation found at 10m is $5.794e^{-05}$m and Equivalent Stress is $3.6404e^{6}$ Pa.

Prototyping:

The above designs were manufactured using the state of art additive manufacturing technology in the Centre for system design (CSD), NITK. The prototyping process is as follows.

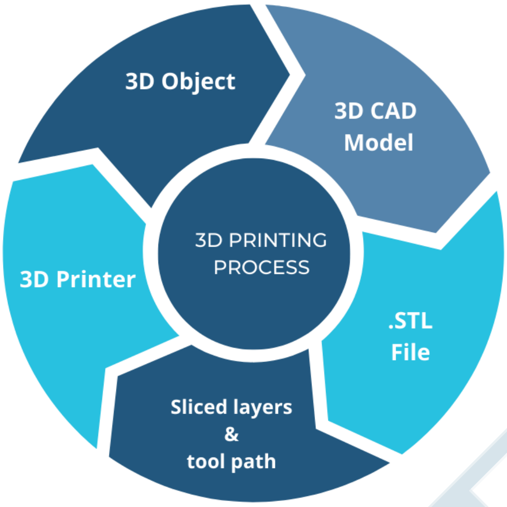

Fig 8: 3D Printing Process

The 3D CAD model is developed using SOLIDWORKS and it will be stored as .STL format. The information about the 3D model is saved in an STL file. The format depicts a model's raw surface, which is made up of small triangles. The STL file is then imported [5]to the MakerBot Print, a slicer software that offers the easiest way to prepare, preview, manage and monitor your 3D print files. This allows us to change the parameters and create a physical model. The printing parameters are given in the below table.

Table 1: Printing Parameters

Parameters	Values
Layer height	0.2mm
First layer height	0.25mm
Infill density	100%
Infill type	Lines
Speed infill	20mm/s
Travel	130mm/s
First layer speed	20mm/s
Extruder temperature	233 ^{0}C
Extrusion multiplier	1.5
Material Diameter	1.75mm

Using above parameters, the nose cone and Tail cone were developed using Poly Lactic Acid (PLA) Material. It is a thermoplastic monomer extracted from renewable, organic sources like corn starch/sugar cane. Here are the general properties of PLA:

Table 2: PLA - Mechanical Properties

Property	Value
Melting temperature	130–180 ^{0}C
Withstand temperature	110 0C
Tensile Strength	50 MPa
Impact Strength - IZOD	96.1 J/m
Flexural Strength	80 MPa
Density	1.24 g/cm³

Fig 9 (a) shows the developed nose cone with a modified design for the seating of Ping sonar which will measure the depth. The nose cone has a[4] diameter of 165mm and a height 80mm. Similarly, the tail cone is shown in fig 9 (b). And it has a diameter of 165mm and a height of 155mm.

(a) **(b)**

Fig 9: 3D Printed (a) Nose cone (b) Tail cone

V. RESULTS AND DISCUSSION

This work mainly focuses on the design, development and implementation of nose and tail cones for underwater vehicles using 3D printing technology. The developed CAD model is analyzed for the drag and failure pressure. It is found that the drag of 2.8N is obtained for the above boundary conditions. And the model will start deforming at a height of 10m with the equivalent stress of $3.6404e^{+6}$ Pa. The product is then manufactured using[6] FDM technology using MakerBot Replicator plus a 3D printer using PLA material. The printed time for both tail and nose cone are 27hrs. Once all the designing and prototyping stages have been completed, the developed nose and tail cones were implemented into the vertical profiler. The reverse thrust from the thruster was able to get the vehicle to the surface faster rate compared to the previous design.

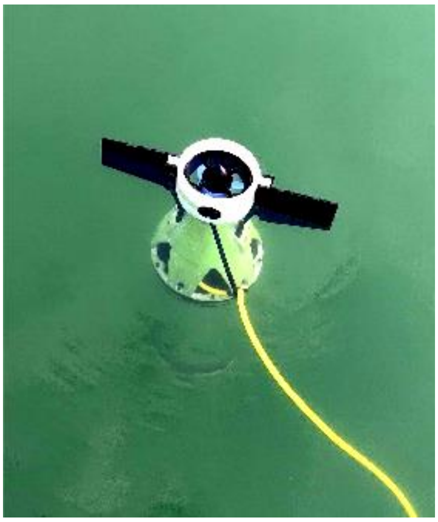

Fig 10: Testing of vertical profiler at swimming pool after implementation of nose and tail cone

The vehicle has a thruster above the nose cone which drives the vehicle. The water pushed from the thruster will directly hit the tail cone at a speed of 4.5m/s which will create a pressure of 0.4bar at the tail cone end. The drag analyzed at the tail due to the geometry is 2.8N which is lower when compared with the thruster force i.e., 49N.

VI. CONCLUSION

The major reason for the underwater survey is to understand the phenomenon inside the water bodies. To collect the data, underwater vehicles were used. The primary agenda of this work is to minimize the cost of the underwater vehicle using 3D printing technology, along with minimizing the drag on the vehicle. Tested model shows us that use of 3D prints in underwater vehicle can be further extended to other field such as development of buoy and stabilizer for underwater vehicles. The vertical profiler with nose cone and tail cone tested for the depth of 5m in the NITK Swimming pool. The vehicle was travelling in the defined path with very less drag. In future research, the same geometry or further optimized geometry can be analyzed for the drag and pressure with different materials and constructed with multiple technologies and tested with the vehicle for maximum life of the product

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