FEM MODEL OF AN UNDERWATER VEHICLE THRUSTER PROPELLER

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ABSTRACT

Propulsion research has been done within the context of the project for the design and optimisation of the Remotely Operated Vehicle (ROV). CFD and FEM simulations that took the undersea vehicle's properties into consideration supported the whole project. Optimising the semi-open duct for horizontal propellers—a quantifiable system that offered controllability and propulsion in a horizontal plane—was one of the goals. It was required to examine the construction of propellers with nozzles and contra-rotating propellers, as well as the numerical approach of propeller design, in order to build a model for this work. Theoretical solutions were presented to it, one of which included operating the examined propeller close to an underwater vehicle. Additionally, first qualitative studies of a streamlined system with a semi-open duct and contra-rotating propellers were performed. Making a choice on the ROVs duct shape was made possible by the findings acquired. An actual propeller model was created using the SLS (Selective Laser Sintering) fast prototyping technique. This meant that the propeller's FEM model, which was based on the load determined by the CFD model, had to be verified. The features of the investigated ROV, the theoretical foundation for propeller design for the situations under analysis, and the outcomes of CFD and FEM simulations are all included in this paper.

1.Introduction

Underwater vehicles are useful tools for investigating ocean mineral resources since they fall within the intersection of ocean engineering and robotics study. Due to its low motivation, poor sustainability, inability to withstand crises, and performance limitations, the undersea vehicle is a frequent subject of scholarly inquiry. Modern ships and underwater robots favour the ducted propeller, an upgraded version of the propeller, due to its greater hydrodynamic performance and excellent work efficiency. The encircling catheter is used as a drainage system. The form constraint intensifies the fluid velocity disturbance brought on by the propeller's rotation. The gadget can accelerate or decelerate, perform better propulsion, and function as a rudder on tiny ships with the help of the ducted propeller. Owing to its exceptional performance attributes, ducted propellers have found extensive application in maritime engineering machinery.Propeller research in its early stages was an extension and an add-on to the growth of the shipping sector. The approach of propeller theory with the potential flow theory was progressively developed when the design of ducted propellers was first suggested and confirmed to efficiently improve the thrust of high-speed heavy ships. Lifting line theory, lifting surface theory, and panel technique are the three primary guiding theories.

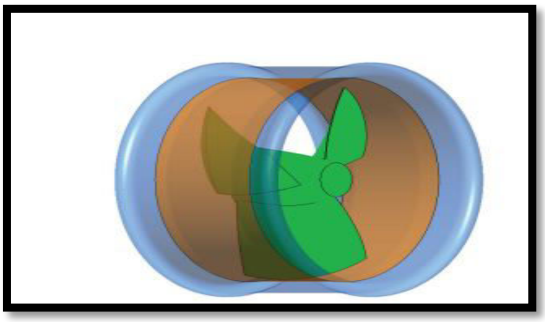

Fig1: Wall counter rotate thruster

These methods have contributed to analysing the hydrodynamic performance of propellers, however, regardless of the fluid viscosity; they still have limitations to a certain degree. Nowadays, depending on the development of computational fluid dynamics (CFD), Reynolds Average Navies-Stokes (RANS) equation used to calculate the viscosity and test verification, has become the main analysis method of hydrodynamic property and motion characteristics for conventional propellers.

Problem Statement

The early identification of the hydrodynamic effects that a mini-AUV experiences during motion is the issue to overcome in this manuscript by:

- The adaptation of a yet-virtually-translated experimental test set to the environment of the CFX on ANSYS Workbench software (ANSYS CFX) may be referred to as the industry-leading computational fluid dynamics software for turbo-machinery applications.
- The simulation of the mini-AUV as a submerged body in the ANSYS CFX environment for determining the forces, accelerations, and velocities during motion.
- The conception of the control laws and the stability study, including the estimated hydrodynamic parameters of the mini-AUV, through the robot manipulator control theory, in order to validate the behaviour of the system.

Objectives

To Design and develop under water thrusters which can be able to designed with propellers facing in a sideways direction so when they are turned on, they push the bow or stern of a sideways through the water, in either direction.

- Analyze the design of Two thrusters 3 and 6 blades and develop in catia v5.
- Materials are used in this project are commercially used thrusters material of AL6061and advanced CFRP material are going to be analyzed.
- To propose a low cost but effective real time thrusters system.
- Performed the static analysis find out the von-misses stress, shear stress, Total deformation.

2. Literature Review

The papers collected could be broadly classified into theoretical study on propeller strength and experiential studies on propeller strength and a few on composite materials and their fem treatment.Xiang X., Yu C **[1]** To combine both theoretical and experimental investigations. The author carried out the measurements of deflection and stresses on model blades subjected to simulated loads with an aim to develop a theoretical model calibrated against the laboratory experiments. Brito M.P. **[2]** "Case Study on the Structural Failure of Marine Propeller Blades" investigated the main sources of propeller blade failures and resolved the problem systematically. An FEM analysis is carried out to determine the blade strength in model and full scale condition and the range of safety factor for the propeller under study is determined. Yao H., Wang H et al **[3]** however, this test method generally has limitations due to its cost and the need for specialized equipment and facilities. With the improvement of computational fluid dynamics (CFD) and high-performance computing (HPC) capabilities, CFD numerical simulation based on self-propulsion model tests provides a new direction for manoeuvrability prediction and research and is well suited as a complement to experimental studies, although validation may require experimental results. Lack S., Rentzow E et al **[4]** the CFD results are compared with the self-propelled model tank test results to verify that the propulsion performance of the two methods is in good agreement at the speed of 1.75 m/s (thrust coefficient KT, torque coefficient KQ propeller efficiency η). However, since the model test and numerical simulation of the propeller require significant computational costs, the study was limited to calculating the trajectory velocity and acceleration of the UV at one-DOF only. Cardenas P., De Barros E.A **[5]** carried out a three-DOF zigzag manoeuvre simulation of SUBOFF in the horizontal plane.

As there were no test results of free-sailing self-propulsion, he adopted two methods (direct simulation of the propeller and body force to replace the propeller) to compare the accuracy.Hnatiuc M., Sabau A., Chetehouna K. **[6].** With the enhancement of computing performance and the development of dynamic grid and other technologies, the simulation of UV manoeuvres took the ship, propeller and controlling planes into consideration at the same time. Meanwhile, more attention was paid to the attitude of a UV during navigation. Karras G.C., Bechlioulis C.P et al **[7]** carried out a series of six-DOF numerical simulations of the general submarine model Jobber BB2 (designed by MARIN) based on self-propulsion and self-sailing tests, including self-propulsion near the surface and at depth, turning circles, vertical and horizontal zigzag manoeuvres at depth, and rise to the surface manoeuvres with stops by crash-back. The calculation was modelled after the principle of the autopilot in the test model. Zhang H et al **[8]** explored the ability of the CFD method to predict the six-DOF free-sailing makeover of a fully appendage UV based on the commercial software Yoon H.K., Nguyen T et al **[9].** The study adopted movable control planes and a body force propeller represented by an actuator disk incorporating predetermined propulsion properties. The aft control planes were X-shaped and consisted of four independent planes; the horizontal and vertical motion of the UV was controlled by autopilot using a proportional-differential (PD) controller that has proportional and differential coupling control parameters. Ridao P., Batlle **[10]** established the credibility of the CFD free-running simulation results. A CFD study of a UV is surely more complicated and difficult compared with surface ships due to the increase in the vertical degrees of freedom (pitch and heave). Since vertical control is related to the safe navigation of a UV, its prediction should be important as well. El-Fakdi A **[11]** simulated a submarine's rising manoeuvres in still water and waves and analyzed the feasibility and potential of a submarine's emergency buoyancy manoeuvrability in a harsh environment through direct numerical simulation. Ridao P.**[12]** used the multi-block hybrid grid and removable region method to simulate a UV-forced self-propelled diving manoeuvre, summarized and analyzed the manoeuvrability of a UV diving motion qualitatively. Cely J.S **[13]** used dynamic grid technology to numerically predict a submarine's vertical zigzag manoeuvrability and verified the feasibility of the CFD calculation with experimental results. This study aimed to comprehensively analyze the turning ability as well as the rising and submergence abilities in the vertical direction.

3. Methodology

Underwater operation vehicle should have basic functions of floating and walking in water, and realize various movements such as forward, steering, backward, floating and sinking. As the power source, the propeller's layout directly affects the direction of thrust and operating performance. The underwater operating vehicle needs to be equipped with a variety of operating equipment, requires a relatively large propulsive force. Designed for underwater operations, the operating vehicle can rotate in the state of landing, so the steering performance requirements in water can be appropriately reduced. The selected layout of the propellers, this arrangement can provide sufficient thrust in the main forward direction and heave direction, and have quite good trim and heel performance. The operating speed of the underwater vehicle usually does not exceed 1 m/s. Therefore, propeller blade matched with the conventional duct is selected as the ducted propeller. According to the selected propeller layout, the three-dimensional model of the underwater operation vehicle integrating with the ducted propellers is developed; the length, width and height of the model.

Materials Selection

AL6061: Excellent joining characteristics, go acceptance of applied coatings. Combines relatively high strength, good workability, and high resistance corrosion; widely available. The T8 and T9 tempers offer better chipping characteristics over the T6 temper.

CFRP: Carbon fibre-reinforced plastic (CFRP) is a very advanced material. With qualities that dwarf those of steel and aluminium, it is continuously discovering new applications and has already become indispensable in a variety of fields.

Table 1: Material properties

PROPERTIES	CFRP	AL 6061
Density(g/cm3)	1.60	2.7
Passion's Ratio	0.10	0.33
Young's Modulus (G Pa)	110	71.7
Ultimate Tensile Strength (M Pa)	600	572

Part Design Workbench

The Part Design workbench is a parametric and feature-based environment in which you can create solid models. The basic requirement for creating a solid model in this workbench is a sketch. The sketch for the features is drawn in the Sketcher workbench that can be invoked within the Part Design workbench. You can draw the sketch using the tools in this workbench. While drawing a sketch, some constraints are automatically applied to it.

Design Procedure In Catia

Propeller Diameter: D = 0.22 m
hub diameter: DH = 0.04 m
number of wings: z = 3
surface coefficient: AE/AO = 0.65
pitch coefficient for 0.7R: P/D = 0.9845
profiles type: NACA16

The thrusters were developed by using full parametric 3d modelling software called CATIA V5 R20. By using above mentioned dimensions are set to be developed entire model of thrusters developed by using the above mentioned dimensions. The following figure shows thrusters multiple views.

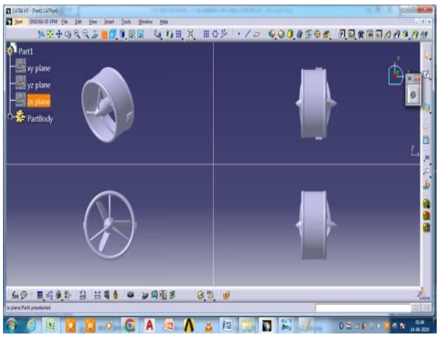

Fig 2: Multiple views of thruster

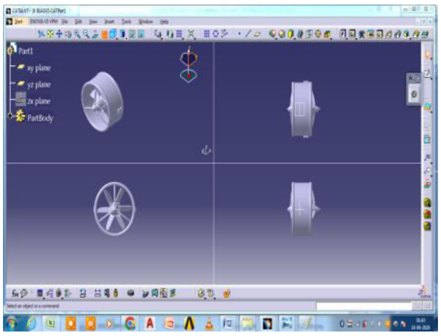

Fig 3: Multiple views of thruster

Mesh And Boundary Conditions

The static structural analysis calculates the stresses, displacements, strains, and forces in structures caused by a load that does not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that the loads and the structure's response are assumed to change slowly with respect to time. A static structural load can be performed using the ANSYS WORKBENCH solver. The types of loading that can be applied in a static analysis include:

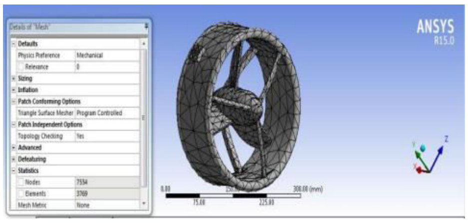

Fig 4: Mesh: Elements:7554, Nodes: 3769 for 3 propeller

Mesh and boundary conditions are crucial aspects in numerical simulations, especially in finite element analysis. Mesh refers to the discretization of the computational domain into small geometric elements. These elements could be triangles, quadrilaterals, tetrahedra, or hexahedra, depending on the type of analysis and the complexity of the geometry. A finer mesh captures more detail but requires more computational resources.

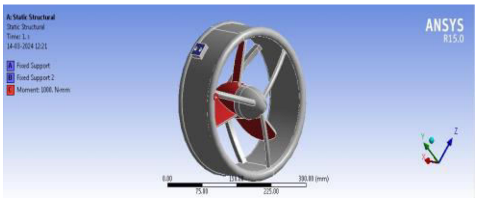

Fig 5: Moment 1000 N.mm

Boundary conditions define how the model interacts with its surroundings. They specify constraints, loads, or other conditions at the boundaries of the computational domain. For example, in structural analysis, boundary conditions could include fixed displacements, applied forces, or prescribed displacements.

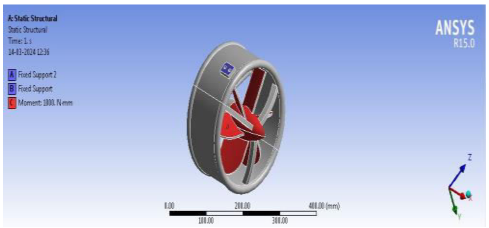

Fig 6: Moment 1000 N.mm for 6 propeller

Results And Discussions

These are the static structural simulations conducting on AL6061, CFRP materials with 3 propellers and 6 propeller using Statically we are finding von-misses stresses, Total deformations, Shear stresses acting on Thrusters are shown in below figures

Uav 3 Propeller :

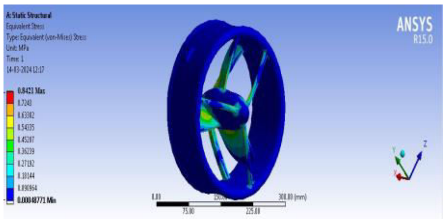

Fig7: Von-misses stress of Al 6061 material

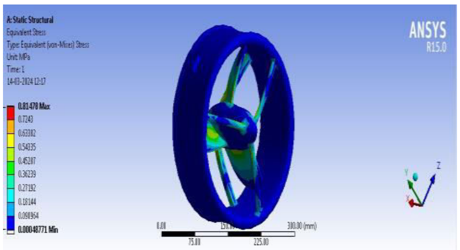

Fig 8: Von-misses stress of CFRP material

For 3 propeller the above diagram shows the load is applied on the ends of thruster. The propeller thruster is loaded with 1000N-mm momemt and slight bend is seen on rotor.

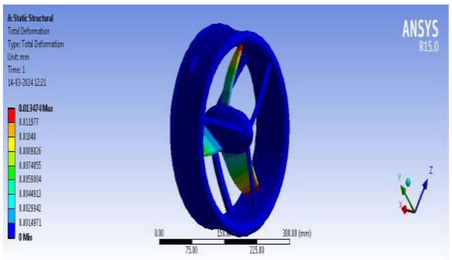

Fig9: Total deformation of Al 6061 material

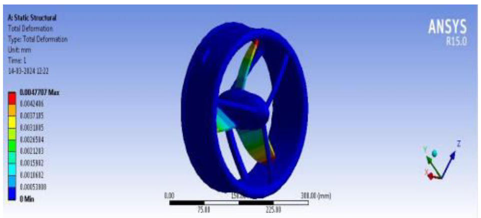

Fig 10: Total deformation of CFRP material

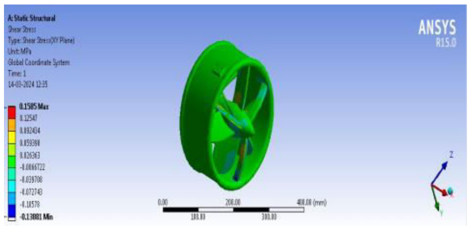

Fig 11: Shear stress of Al 6061 material

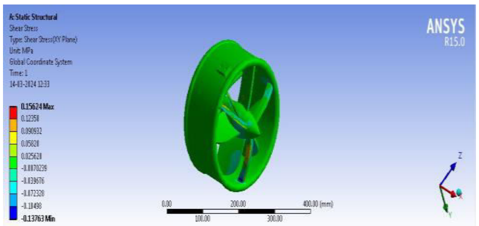

Fig 12: Shear stress of CFRP material

Uav 6 Propeller :

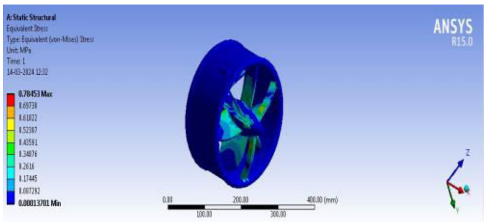

Fig 13: Von-misses stress of Al 6061 material

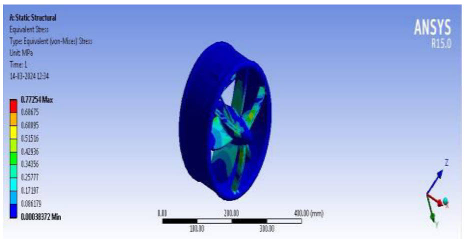

Fig14: Von-misses stress of CFRP material

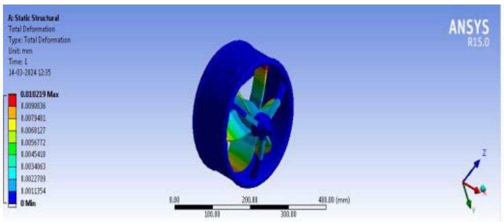

Fig 15: Total deformation of Al 6061 material

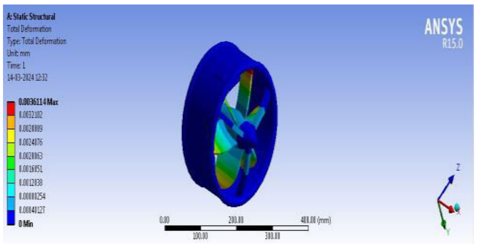

Fig 16: Total deformation of CFRP material

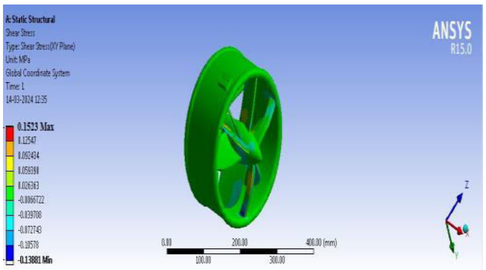

Fig17: Shear stress of Al 6061 material

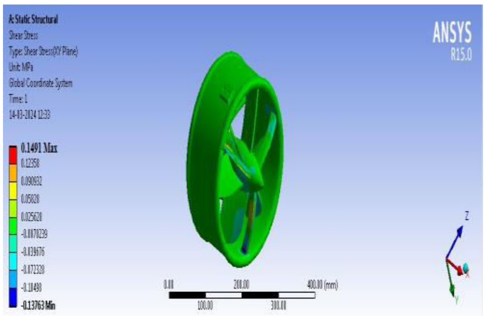

Fig 18: Shear stress of CFRP material

Von-Misses Stress

From below figure we can observe that in case of equivalent (von-misses) stress, THRUSTER made up of AL6061 and CFRP materials. Finally observed to have least von-misses stress CFRP Material 0.699 M pa compared to AL6061 materials as shown below fig.

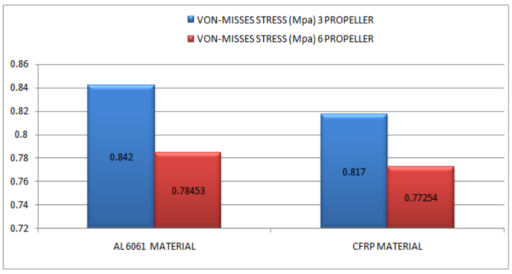

Fig 19: Von- Misses Stress

Total Deformation Graph

The figure was observed that in case of equivalent total deformation acting on THRUSTER made up of AL6061 and CFRP materials. Finally observed to have least total deformation on CFRP Material 0.0000445 mm compared to AL6061 materials as shown below fig.

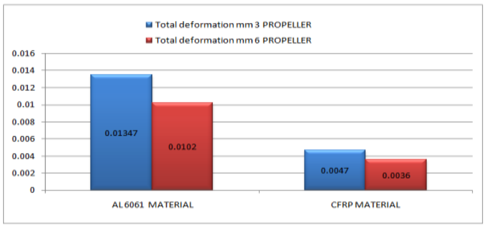

Fig 20: Total Deformation

Shear Stress

From below figure we can observe that in case of shear stress, THRUSTER made up of AL6061 and CFRP materials. Finally observed to have least shear stress CFRP Material 0.119 M pa compared to AL6061 materials as shown below fig.

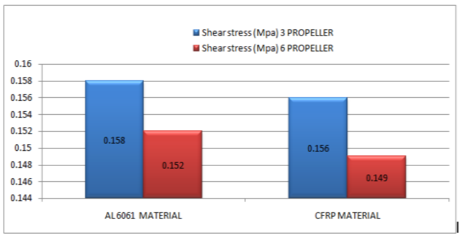

Fig 21: Shear Stress

CONCLUSIONS

Using the findings of the FEM model and an assumed safety factor of 1.5, it was discovered that an aluminium propeller manufactured by the fast prototyping (SLS) process could safely transmit the dynamic load produced during operation. Furthermore, a little deformation of the material shouldn't have a major impact on the propeller's efficiency or hydrodynamic properties. The steps to build a computational approach based on FEM for structures generated in the aforesaid process have been taken in order to test the performance of items manufactured using a rapid prototyping method. In the end, more experimental strength testing will confirm the effectiveness of this approach. The suggested technique of computation requires additional refinement, namely in the area of simulating the interference between the propeller and nozzle. This result stems from experimental tests conducted on the job in question from the perspective of hydrodynamics phenomena. Nevertheless, given that next phases of the project will include evaluating the ROV design solution and that the use of semi-open ducts for horizontal thrusters would be predicated on qualitative rather than quantitative analysis, the current findings are adequate. Lastly Based on the stresses, deformations, and shear stresses, a propeller with six CFRPs is the optimum option.

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