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Design and Analysis of Three Bearing Swivel Duct Nozzle on Rescue Boats

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Abstract. Water jet propulsion is a type of propulsion system which is used in boats for high-speed operation. This method of propulsion provides higher speed and greater manoeuvrability to the vessel. Our project's aim is to replace the conventional water jet nozzle in jet propulsion with a three-bearing swivel duct nozzle also known as 3BSD nozzle. The nozzle consists of three ducts which changes the axis of water jet to the required direction. For the rotation of the ducts, gears are provided. The nozzle can be rotated up to 90 degree with the combined motion of three ducts. The mechanism of nozzle reduces the turning radius of vessel to a great extent. We are planning to implement this design in the rescue boat which requires greater speed and better steering capability. This also provides protection from the rotating elements like propeller blades, making the operation safer around swimmers and aquatic life. This nozzle provides vectored thrust. We have done computational fluid dynamics analysis(CFD) to find the flow characteristics and load variation in the nozzle.

INTRODUCTION

The water jet propulsion boat works on Newton's third law which states that, for every action there is an equal and opposite reaction. The force of the water jet ejected from the nozzle of the boat create a reaction force. This reaction force is used to move the boat forward. The water is directly taken from the inlet duct which is placed below the boat. In most cases only one inlet duct is used. If the power requirement is high, higher number of ducts can be used. The fluid from the bottom of boat is taken by the suction produced due the propeller. The inlet water is of low pressure in order to produce higher pressure. The water is subjected to turbulence using the propeller blades. The propeller blades are powered using the on-board high-power motor. The motor convert the water to a high-pressure high-energy fluid. The high-pressure water is ejected as jet through the nozzle.The nozzle is placed in the aft of the boat and it directs the fluid leaving the system[1]. The nozzle is controlled by swivel system that is connected to the steering wheel. The nozzle can be rotated up to 90º using gear mechanism. In order to attain the reverse direction the flow must be reversed where the outlet of flow must be through the inlet duct[2].A three-bearing swivel duct consists of three rotatable ducts. These ducts are rotated to certain degree in order to change the direction of outlet water jet. For the rotation of ducts,three motors are provided. Ball bearing is used in between two ducts to reduce the friction between moving parts. A control unit system is required which connects to the steering of the boat which controls the rotation of ducts.

The main reason for choosing jet propulsion boat is due to the speed of vessel. For small vessel, water jet powered boats are able to attain 40 knots (75 kmph). This is very high compared to normal conventional boats. The water jet propulsion system is compact and is able to produce large amount of power within a small unit. Since the propeller blades are covered, it prevents any types of accidental contact.Since the steering is almost instantaneous, water jet propulsion boats are easy to manoeuvre. This is because of the swivel duct mechanism that changes the angle of outlet nozzle. Compared with conventional vessels jet propelled boat requires only less turning radius. Steering and navigation are faster and more efficient. Water jet propulsion produces less sound compared to conventional propulsion[3].

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METHODOLOGY

Methodology including the work plan:

- Theorizing and generalizing the concepts
- Designing the model using cad
- Fabrication of the prototype model
- Simulation process

Theorizing and Generalizing the Concepts

The idea of the three-bearing swivel duct was taken initially from the nozzle which was designed for the fighter aircraft for VTOL and STOL actions. This nozzle also helped to increase the thrust vectoring capabilities of the aircraft. The idea is to re-design a 3-BSD nozzle which can be used in rescue boats, which helps the need of the boats to enter any tight corners and narrow paths during a flood situation or any attempt that satisfies the need of this idea. The concept and the working mechanism of the 3BSD nozzle was studied and the initial steps were taken to design the nozzle in an economical way and to reduce the cost of production. The nozzle is designed to act also as a protective cover for the propeller when it is used in shallow waters or during any rescue operations[4].

Designing the Model Using CAD

The model is designed in CAD software(Figure 1) using specified dimension to fabricate the model and to perform analysing. The idea of this project is to create two solidmodel design usingCAD software in which one is designed in actual size for a propeller of outer diameter of 12 inch and a prototype model design which is 3 times smaller than the actual design.

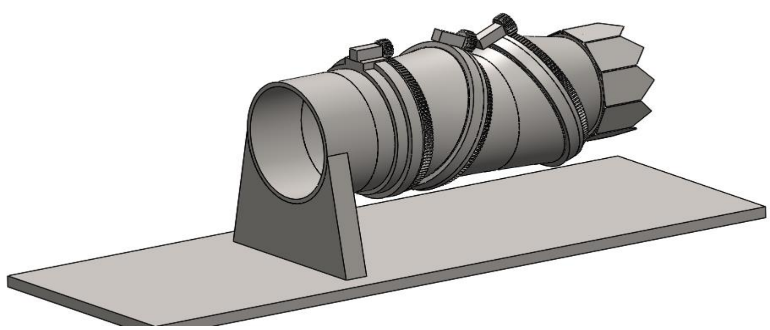


FIGURE 1. *Solid model of the nozzle.*

Fabrication of the Prototype Model

The model is designed in cad design software, the designed model is 3D printed using PLA material.There are a total of 24 components of the 3BSD nozzle which was printed with an appropriate printing hours of 35. It includes three main ducts, one housing, two support rings, three ball rings, three brackets, three pinion, three ring gear, one housing duct and a converging nozzle (Figure 2). The material which is used to print the components was PLA (polylactic acid) having a diameter of 2.85mm.After the completion of the printing, the parts were assembled, and the working of the model were verified.

FIGURE2. *Parts of 3 BSD nozzle.*

Simulation Process

The model is simulated on ANSYS simulation software with given constrains and assumptions.

DESIGN PROCESS

The Geometric Model of 3BSD

TheFigure 3is a schematic diagram of the profile of 3BSD at the maximal yaw angle, Suppose the maximal yaw angle of 3BSD is β, and the bevel angle of duct 2 and duct 4 is α. From the figure, it can be concluded that α and β satisfy the following relationship.

$$\alpha = (\pi /2) - ((\pi-\beta/2)/2) = \beta/ 4$$
$$\alpha = (\pi /2) - ((\pi-90/2)/2) = 22.5°$$

As per the above equation the ducts of the 3BSD nozzle should be inclined at an angle of 22.5 degree to achieve the 90-degree complete transition for the nozzle[5].

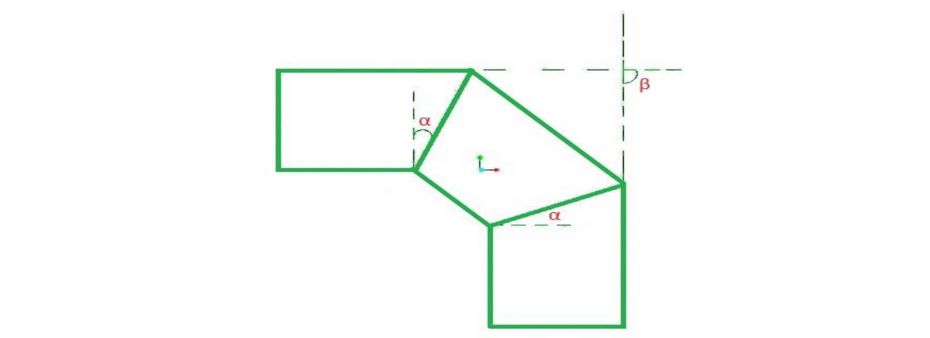


FIGURE 3. *Section at 90^o rotation.*

Components and Specification of 3BSD Nozzle

Duct 1 and Housing

Duct 1 was designed having inner diameter and the outer diameter of the duct was 100 mm and 108 mm and the design was extruded 30mm (Figure 4a). For the purpose of analysing, the duct 1 was scaled to 3 times its design dimension. The material used for the fabrication was PLA. Stainless steel is selected for the purpose of analysing the material for duct. The housing was designed in such a way that the inner and outer diameter of the duct were 108mm and118mm, and the design was extruded 20mm (Figure 4b). For the purpose of analysing, the duct 1 housing was scaled to 3 times its design.The material used for the fabrication were PLA.

(a) (b)

FIGURE4. *(a) Duct 1; (b) Duct housing.*

Duct 2 and Duct 3

The duct 2 was designed to have an inner and outer diameter of 100mm and 102mm and the design was extruded 61mm (Figure 5). The duct 2 is the first rotating component of the 3BSD. There are two circular profile for this duct in which one is designed as same as the above dimension and other circular profile is angled at 22.5 degree to the clockwise direction from the horizontal axis of the duct 2.The second profile of the duct 2 has an inner diameter of 108mm and outer diameter of 130mm. The outer periphery of the duct from the inlet side has a contour through which the ball ring is placed for the smooth rotation of the duct 2. Adjacent to it, gear is placed and in the inner periphery at the outlet side has a contour in which the duct 3 is placed along with the ball ring of the duct 3. Since duct 2 and duct 3 are not fixed to each other, the duct 3 is also a rotating component of the 3BSD nozzle. There are two circular profile for this duct in which the inlet profile for this duct has the same dimension as duct 2 but this profile is inclined at an angle of 22.5 degree to the clockwise direction and other circular profile is angled at 22.5 degree to the anti-clockwise direction from the horizontal axis of the duct. The two circular profiles have the same dimension as the previous duct.

(a) (b)

FIGURE5. *(a) Duct 2; (b) Duct 3.*

Duct 4 and Nozzle

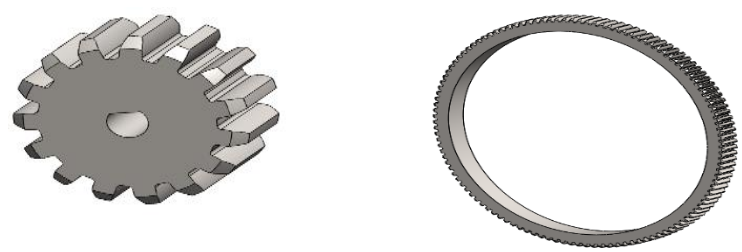
This duct is designed in a shape of a converging nozzle to increase the fluid velocity at the outlet. The duct 4 is the final rotating component of this 3BSD nozzle in which the circular profile at the inlet side is same as the duct 3 and this profile is inclined at an angle of 22.5 degree to the anti-clockwise direction from the horizontal axis of the duct. The inner and the outer diameter of this duct at inlet is designed to be same as the inner and outer diameter of duct 3.The duct's second circular profile is having inner diameter of 82mm and outer diameter of 88mm, which is for the purpose to attain a design of converging nozzle. The nozzle is designed to be fixed with duct 4 outlet section which is having an inlet diameter of 88 mm and outer diameter of 94 mm (Figure 6).

(a) (b)

FIGURE 6.*(a) Duct 4; (b) Nozzle.*

Pinions and Gears

The pinions were designed to rotate the ducts, which is fixed to the shaft of the N20 gear motors. There are mainly two types of pinions used, each having different pitch diameter.A total of 3 pinions were designed and printed for the working of the 3BSD nozzle. The module of the pinions was 1 and the pitch diameter of the pinion was 15mm and 19 mm respectively. The number of teeth for each of the pinion were 15 and 19. The module for each gears was same as the pinions for proper meshing which is 1 and the pitch diameter was 120mm and number of teeth for each gear were120mm (Figure 7). Each gear was placed over the ducts and the inner diameter for each gears was corresponding to the outer diameter of the duct. The gears were extruded to 9mm and total of 3 gears were printed[6].



(a) (b)

FIGURE 7.*(a) Pinion; (b) Gears.*

Ball Rings and Supporting Ring

The ball rings were designed to rotate the ducts and they were placed at duct 2, 3 and 4 in the contours which are at the inlet of each ducts. The idea of the ball ring was taken from the concept of ball bearing.This has helped to rotate the ducts and reduced the overall cost of the design by using a single ball ring for each duct instead of using several ball bearing for a single duct. The ball rings were designed in such a way that the inner diameter and the outer diameter of the ball rings were 113mm and 115 mm and extruded to 10mm. The spherical balls were 6mm in diameter.A total of 10 spherical balls were used and placed in holes which is designed on the surface of the ring. The supporting rings are designed to fix the ducts and the ball rings close to each other and keep the ducts in a fixed position.It assists the ducts to rotate without being pulled away since the ducts are not fixed to each other. The support ring has an internal diameter of 118mm and outer diameter of 130mm (Figure8).The design is extruded to 4.25mm[7].

(a) (b)

FIGURE 8.*(a) Ball ring; (b) Support ring.*

ASSEMBLY

Initially the components used to rotate the ducts were assembled, which includes the arrangement of spherical balls inside the ball ring (Figure 9).The alignment with supporting ring was also checked. The duct 1 is placed inside the housing designed for duct. The gears are placed over the duct and ball rings are placed in the contours made for them in each ducts. The ducts are arranged in a coincident to each other and the support rings are glued to the ducts to fix the ducts firmly in their positions. The nozzle is also glued to the outlet side of duct 4. The next step is to assemble the pinions. The pinions are fixed to the shafts of the N20 gear motors and with the help of brackets the motors are fixed firmly to their respective ducts. The motors along with pinion are arranged with the gears in such a way that the mating of gears should occur without any interventions and the circuit is connected to a bi-directional switch which helps to change the polarity of the motor according to the operation needs. The circuit from the switches are connected to a power source of 9v battery and the circuit is completed. The working of assembly is checked by turning the switch to on position and the working of the 3BSD nozzle is verified.

FIGURE 9.*Assembled 3BSD nozzle.*

WORKING

The design consists of mainly 4 ducts in which the rotating ducts are duct 2, duct 3 and duct 4. These ducts are rotated by the gear. Thepinion rotates the gear which is fixed to the periphery of the ducts. When the circuit is turned on the motor shaft rotates along with the pinion which mates with the gear and rotates the ducts.

For Sideways Rotation

The rotation of the 3BSD nozzle is done in such a way that the duct 4 is rotated 180 degree in clockwise direction using the gear which is placed in the duct 4 and the pinion which is fixed in the N20 motor on the duct 3 which is operated by switching the bi-directional switch 3 to ON condition (Figure 10). After the completion of the rotation the switch is turned OFF, thus restricting the further rotation of the duct 4. The next step is to rotate the duct 3. The duct 3 is rotated 180 degree in counter clockwise direction using the gear which is placed in the duct 3 and the pinion which is fixed in the N20 motor on the duct 2 which is operated by switching the bi-directional switch 2 to ON condition. After the completion of the rotation the switch is turned OFF, thus restricting the further rotation of the duct 3. At the end of the rotation of the duct 2 the 3BSD nozzle will attain its 90-degree shape. The final step is to rotate the duct 2.The duct 2 is rotated 90 degree either in counter clockwise direction or in clockwise direction according to the operations needed, which includes the sideways rotation.This is done by using the gear which is placed in the duct 2 and the pinion which is fixed in the N20 motor on the duct 1. It is operated by switching the bi-directional switch 1 to ON condition. After the completion of the rotation the switch is turned OFF, thus restricting the further rotation of the duct 1.

FIGURE 10.*Nozzle at 90-degree angle*

ANALYSIS OF 3 BSD NOZZLE

Computational fluid dynamics is done to simulate the fluid motions using analysis software. CFD gives the fluid interaction with nozzle walls and the velocity vectors. The fluid selected for analysis is water. The inlet and outlet section of nozzle is selected, and the inlet velocity is given as 10m/s. The turbulent intensity is given as 5%. The turbulent viscosity ratio is given as 10.

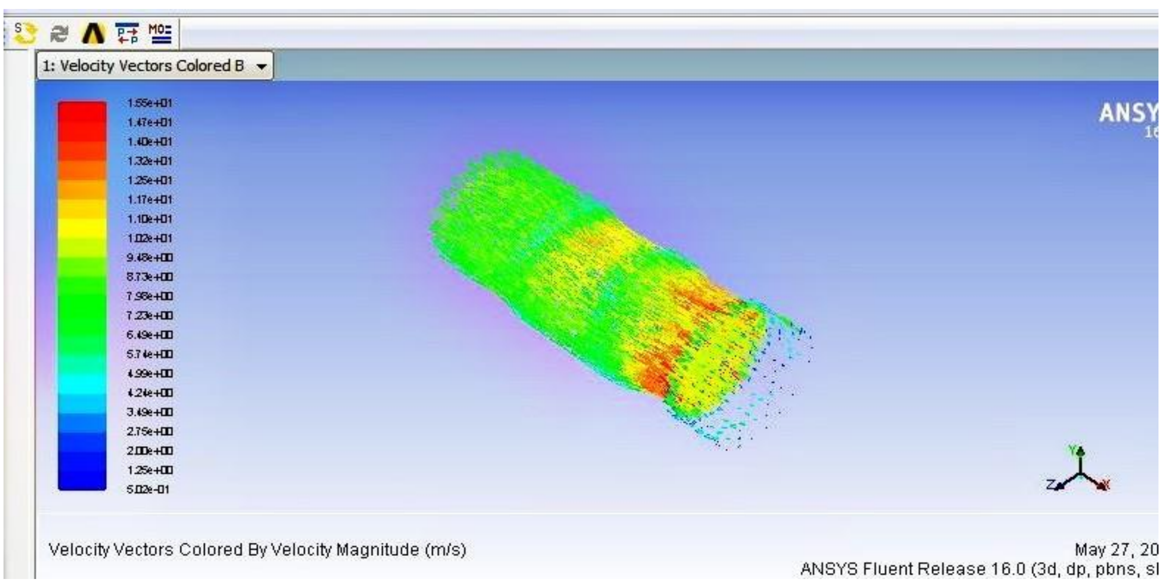


FIGURE 11. *Velocity vectors of the fluid flow at 0°*

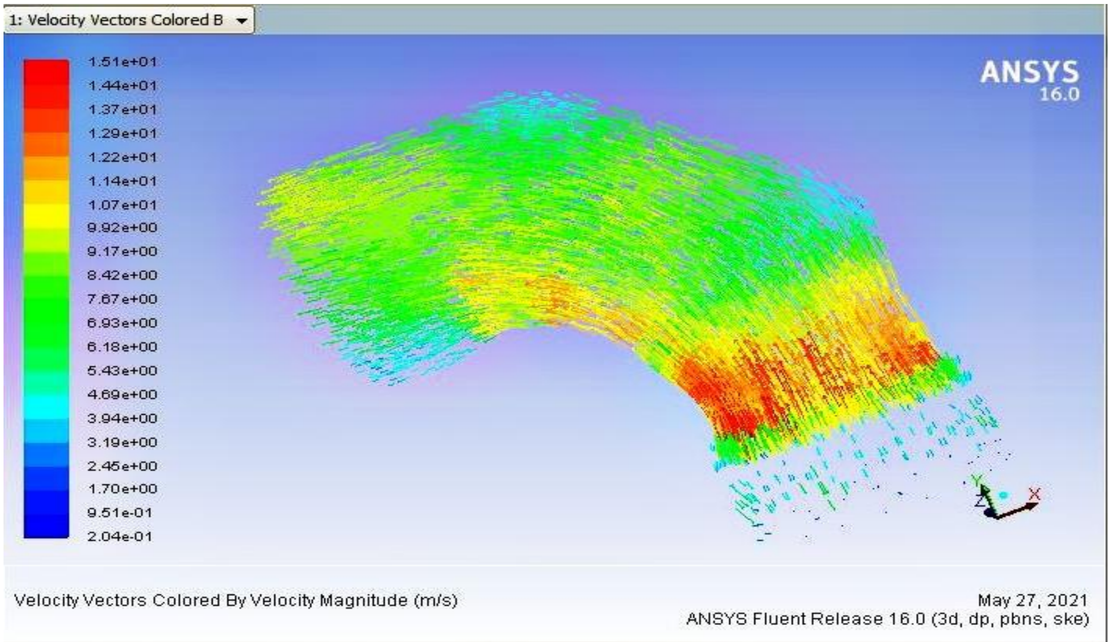


FIGURE 12. *Velocity vectors of the fluid flow at 90°*

From the CFD analysis maximum velocity of water in the nozzle is 15.4614m/s and the minimum velocity inside the nozzle is 0.502m/s. The maximum fluid velocity occurs at the exit of converging section.

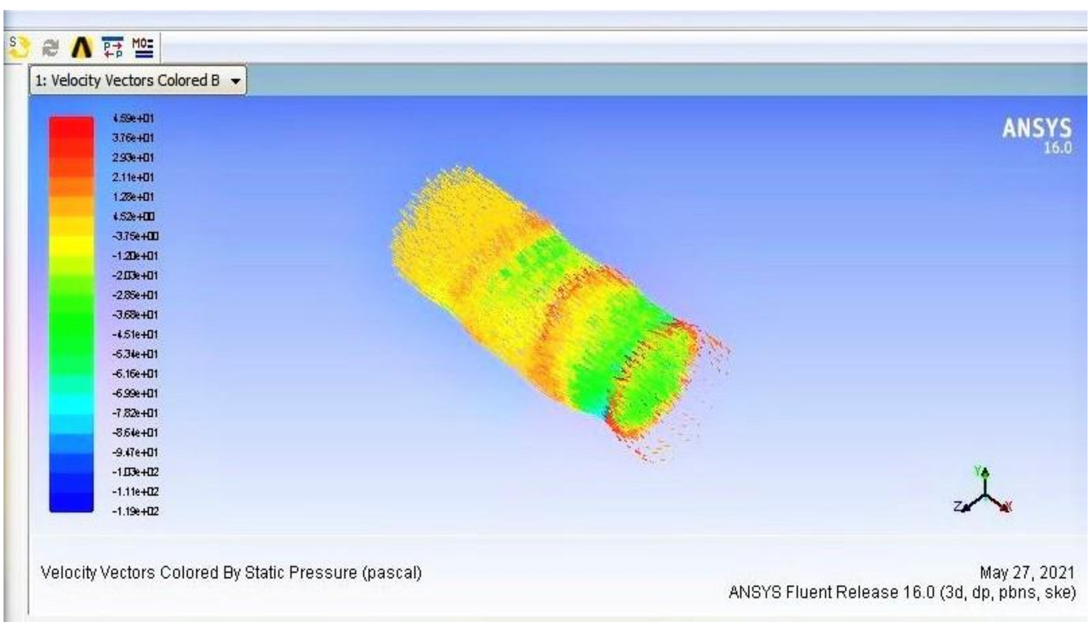


FIGURE 13. *Static pressure at 0°*

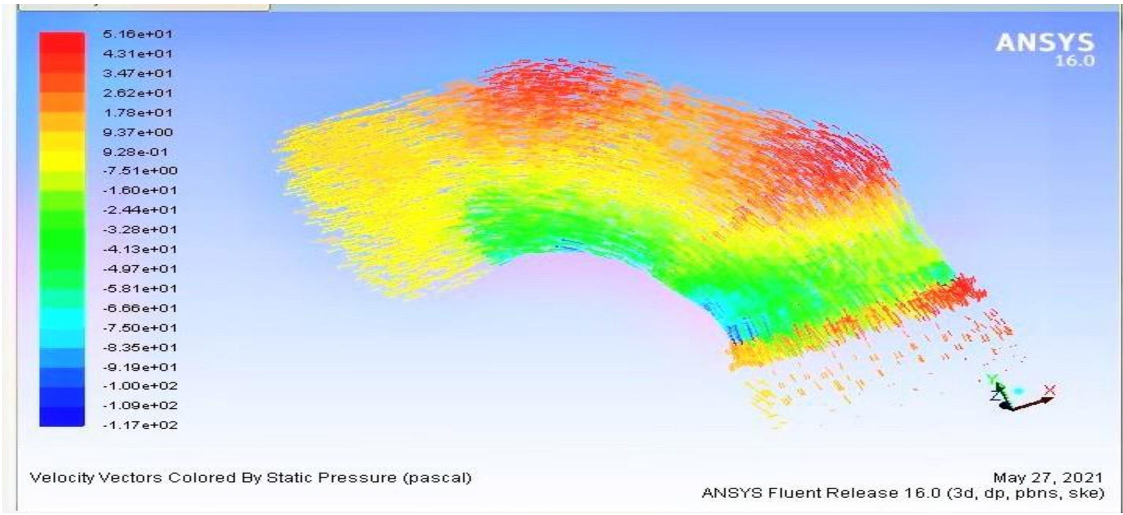


FIGURE 14. *Static pressure at 90°*

The maximum static pressure acting on the nozzle at zero degree is 45.86Pa and minimum static pressure is -119.4556Pa. When the nozzle is rotated to 90^0, the max static pressure is 51.56Pa and minimum static pressure is -117.22Pa.

CONCLUSION

In this paper we have designed and done analysedthe three-bearing swivel duct nozzle which can be replaced with conventional water jet propulsion nozzle. The angular deflection of the nozzle is calculated based on numerical and prototype model. The maximum attainable angle using the nozzle is 90º. The nozzle can be used in rescue boat which requires higher speed and manoeuvrability. The nozzle is tested by making a prototype and the movement of each duct is tested and is working fine. The gear mechanism using to rotate the ducts provides precise deflection to the required direction. The fluid flow and the pressure acting on walls of the nozzle is calculated using the computational fluid dynamics (CFD). The fluid flow is tested in two conditions zero-degree deflection and 90-degree deflection.

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