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Designing of Nozzle for Unmanned Water Powered Aerial Vehicle

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Abstract- This project is used to develop a conceptual design for an UNMANNED WATER POWERED AERIAL VEHICLE (UWAV) that utilizes a waterjet propulsion system instead of traditional propulsion methods such as propellers or jet engines. The project idea is based on the flyboard system where the drone flies with the force generated by water jet from the nozzles and directing the force in required directions. The purpose of the project is to optimize the efficiency of the waterjet propulsion system to achieve maximum thrust while minimizing energy consumption by improving the design of nozzle. This propulsion systems reduces noise generated in conventional UAV's. These types of drones are used for Aquatic ecosystem surveillance, agriculture, cleaning of building without human interface.

Index Terms- UWAV, Waterjet propulsion system, Nozzle, Thrust generation.

I. INTRODUCTION

The unmanned water-powered aerial vehicle used waterjet propulsion system with the help of hose is connected to pump or motor located on jet ski or ship.

These exhibit great potential for implementation in various fields, especially in high-risk environments such as rescue operations. However, their maneuverability depends entirely on the operator skills.

The proposed UWAV utilizes a nozzle rotation mechanism to adjust the water thrust's direction and replace the role of the rider in governing the system's motion. An aerial water-powered vehicle comprises three main components: a water pump, a flexible water hose, and a board assembly. On the board assembly, water is jetted out at the water outlet port, generating thrust force.

The mechanism solutions, primarily classified into three types: weight-shifting, flow-regulating, and nozzle rotation mechanisms. Noise reduction is Beneficial for operations in or near water, where natural absorption and masking can significantly reduce perceived noise. Suitable for tasks requiring stealth or minimal disturbance in aquatic environments.

In this UWAV we used to design conical nozzle due to its Robustness, Light weight, and Altitude adaptability. And inlet thickness of nozzle wall is greater than the outlet wall thickness because of Pressure is high at inlet, Mechanical strength (to avoid system vibration), Redundancy (if any unexpected load during operation, the nozzle will still perform), Assemble (reduce risk damage during installation and maintenance).

II. FUNDAMENTALS OF UWAV

1. Components of a Waterjet Propulsion System.

- **Pump:** The heart of the waterjet system is the pump. It draws in water through an intake and expels it at high speed through a nozzle.
- **Intake:** Located at the bottom of the watercraft (like a jet ski or ship), the intake allows fluid to enter the pump. The intake must be designed to minimize turbulence and maximize flow efficiency.
- **Impeller:** This is a rotating part of the pump that accelerates the water. It works similarly to a propeller but is enclosed within the pump housing.
- **Nozzle:** The nozzle is the exit point where the accelerated water is expelled. The shape and size of the nozzle can affect the thrust and control of the waterjet.
- **Thrust Directional Control:** For a flyboard, the nozzle's direction can be controlled to maneuver and stabilize the board. This is often achieved through manual controls operated by the automated systems.

2. Operation of a Waterjet Propulsion System

- **Water Intake:** Water is entered into the intake, which is typically positioned on the underside of a jet ski or similar watercraft.
- **Water Acceleration:** The water enters the pump, where the impeller rotates rapidly, increasing the water's velocity.

- **Water Ejection:** The high-speed water is expelled through the nozzle. In UWAV, this nozzle is connected to hoses that lead to the drone.
- **Thrust Generation:** The high-velocity water creates thrust, which is directed downward through the hoses and out of nozzles on the drone. This thrust propels the drone upward.
- **Control and Stability:** The transmitter can control the direction of the nozzles on the drone to maneuver and maintain balance. By adjusting the angle and direction of the nozzles, the rider can move up, down, and in various directions.

3. Drone Specifics

- **Hoses (Pipes):** Drone is connected to a jet ski or watercraft via long, flexible hoses. These hoses carry the high-pressure water from the pump to the board.
- **Nozzle Control:** The transmitter controls the nozzles direction according to human inputs. This control allows for maneuvering.
- **Safety Mechanisms (Sensors):** Drones often include safety features such as automatic shutoff if at any malfunction happens or if the hoses become disconnected.

4. Advantages of Waterjet Propulsion

- **Efficiency:** Waterjet propulsion is highly efficient for watercraft, providing significant thrust with relatively low energy consumption.
- **Maneuverability:** The ability to direct thrust allows for precise control, making it ideal for applications like aquatic ecosystem surveillance.
- **Safety:** Since there are no exposed propellers, waterjet propulsion reduces the risk of injury in recreational applications.

5. Applications

- **Aquatic Wildlife Observation:** It can monitor aquatic wildlife and their habitats, providing data for conservation efforts without disturbing the environment.
- **Irrigation Management:** UWAVs can help monitor and manage large irrigation systems, ensuring efficient water use and identifying areas that require attention.
- **Eco-Tourism:** They can offer unique aerial views and experiences for eco-tourism, enhancing visitor engagement and education.
- **Water Rescue Operations:** They can assist in locating and delivering aid to individuals stranded in water bodies during disasters.

6. Problem Identification

- **Size and Weight Constraints:** Water jet propulsion systems can be bulky and heavy, which can be a challenge for drones where size and weight are critical factors. To solve this without compromising the performance is a key problem to address.
- **Energy Efficiency:** Water jet propulsion systems may require significant power, leading to overcome the flight times or reduced payload capacity. Improving energy efficiency in less power consumption are ongoing challenges.
- **Thrust and Speed:** Achieving sufficient thrust and speed with water jet propulsion systems, especially in challenging conditions like strong winds or turbulent waters, can be a problem that affects the drone's overall performance and capabilities.

III. DIMENSION OF NOZZLE

It's an scale down model of conical nozzle, I have scale down model because it will give an acurate result and easy to design.

I have design this model in CATIA V5.
The height of nozzle is 50mm.

Sections	Outer Dimension	Inner Dimension
Inlet	7.5mm	3mm
Middle	10mm	5mm
Outlet	3mm	1mm

At Inlet

- Total radius - 7.5mm
- Wall thickness - 4.5mm
- Inner radius - 3mm

At Outlet

- Total radius - 3mm
- Wall thickness - 2mm
- Inner radius - 1mm

IV. DESIGNING OF NOZZLE

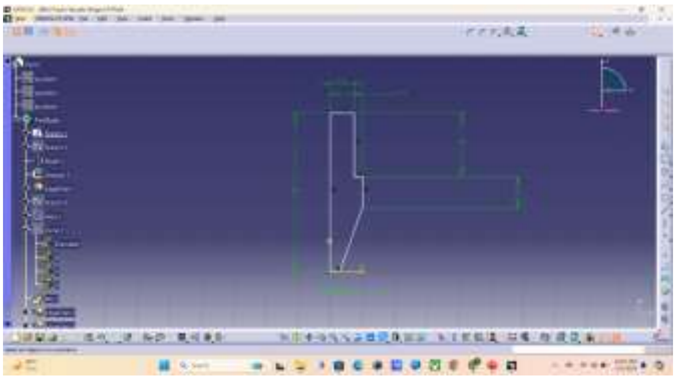

Figure 1 Outer Design

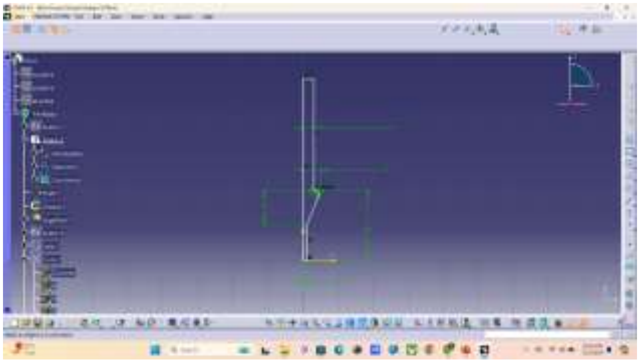

Figure 2 Inner Design

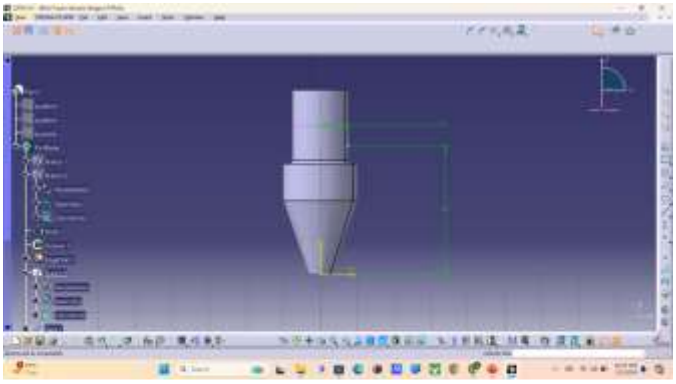

Figure 3 Model After Liability 360 Shaft & For Inner Part Making Groove

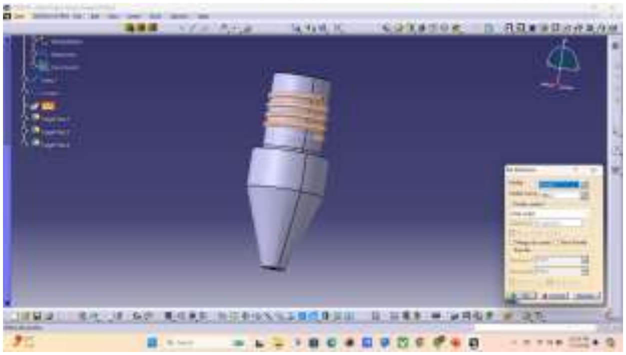

Figure 4 Making Helix Structure Help In Installation

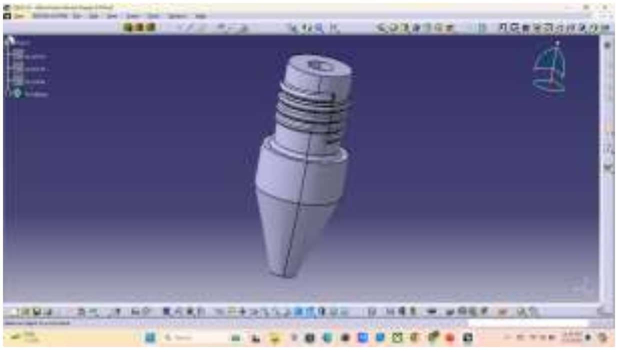

Figure 5 Final Model Of Nozzle

Figure 6 Drawn Inner Part For Analysis

V. ANALYSIS

Analysis is done in ANSYS – Fluid Flow (fluent).

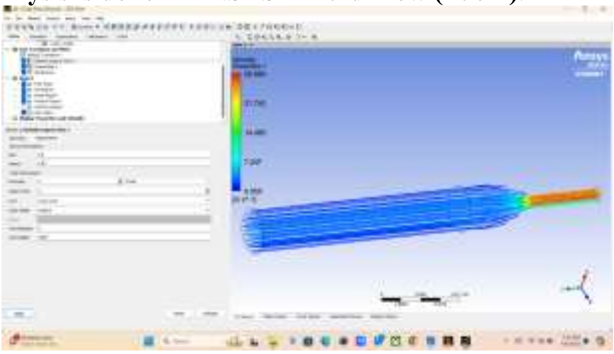

Figure 7 Velocity Analysis In The Nozzle

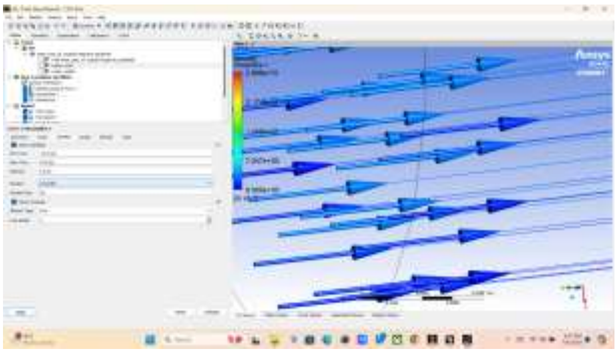

Figure 8 Streamline Flow In The Nozzle

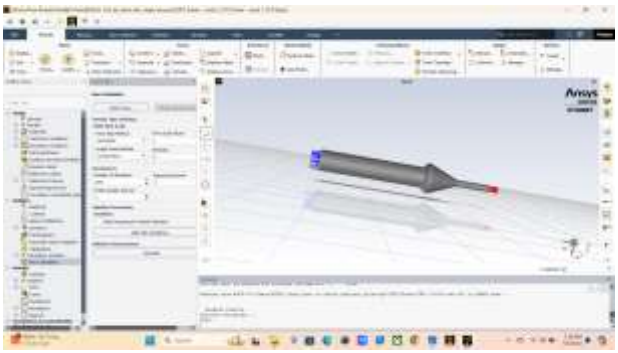

Figure 9 Flow Visualization At Different Variables

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VI. RESULTS

Models

Model	Settings
Space	3D
Time	Steady
Viscous	Standard k-epsilon turbulence model
Wall Treatment	Standard Wall Functions
Heat Transfer	Disabled
Solidification and Melting	Disabled
Species	Disabled
Coupled Dispersed Phase	Disabled
NOx Pollutants	Disabled
SOx Pollutants	Disabled
Soot	Disabled
Mercury Pollutants	Disabled
Structure	Disabled
Acoustics	Disabled
Eulerian Wall Film	Disabled
Potential/Electrochemistry	Disabled
Multiphase	Disabled

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Material Properties

Material: steel (solid)

Property	Units	Method	Value(s)
Density	kg/m^3	constant	8030
Cp (Specific Heat)	J/(kg K)	constant	502.48
Thermal Conductivity	W/(m K)	constant	16.27

Material: water-liquid (fluid)

Property	Units	Method	Value(s)
Density	kg/m^3	constant	998.2
Cp (Specific Heat)	J/(kg K)	constant	4182
Thermal Conductivity	W/(m K)	constant	0.6
Viscosity	kg/(m s)	constant	0.001003
Molecular Weight	kg/kmol	constant	18.0152

Material: air (fluid)

Property	Units	Method	Value(s)
Density	kg/m^3	constant	1.225
Cp (Specific Heat)	J/(kg K)	constant	1006.43
Thermal Conductivity	W/(m K)	constant	0.0242
Viscosity	kg/(m s)	constant	1.7894e05
Molecular Weight	kg/kmol	constant	28.966

Material: aluminum (solid)

Property	Units	Method	Value(s)
Density	kg/m^3	constant	2719
Cp (Specific Heat)	J/(kg K)	constant	871
Thermal Conductivity	W/(m K)	constant	202.4

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Cell Zone Conditions

Zones

name	id	type
inner_part_of_nozzle-freeparts_partbody	3	fluid

Setup Conditions

inner_part_of_nozzle-freeparts_partbody

Condition	Value
Frame Motion?	no
Mesh Motion?	no

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Boundary Conditions

Zones

name	id	type
wall-inner_part_of_nozzle-freeparts_partbody	1	wall
water_inlet	6	velocity-inlet
water_outlet	7	pressure-outlet

Setup Conditions

wall-inner_part_of_nozzle-freeparts_partbody

Condition	Value
Wall Motion	Stationary Wall
Shear Boundary Condition	No Slip

water_inlet

Condition Value

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Velocity Magnitude [m/s]   3

water_outlet

Condition   Value

</BoundaryConditions>

<SolverSettings>
Solver Settings

Equations

Equation	Solved
Flow	yes
Turbulence	yes

Numerics

Numeric	Enabled
Absolute Velocity Formulation	yes

Pseudo Time Explicit Relaxation Factors

Variable	Relaxation Factor
Density	1
Body Forces	1
Turbulent Kinetic Energy	0.75
Turbulent Dissipation Rate	0.75
Turbulent Viscosity	1
Explicit Momentum	0.5
Explicit Pressure	0.5

Linear Solver

Variable	Solver Type	Termination Criterion	Residual Reduction Tolerance
Flow	F-Cycle	0.1	
Turbulent Kinetic Energy	F-Cycle	0.1	
Turbulent Dissipation Rate	F-Cycle	0.1	

Pressure-Velocity Coupling

Parameter	Value
Type	Coupled
Pseudo Time Method (Global Time Step)	yes

Discretization Scheme

Variable	Scheme
Pressure	Second Order
Momentum	Second Order Upwind
Turbulent Kinetic Energy	First Order Upwind
Turbulent Dissipation Rate	First Order Upwind

Solution Limits

Quantity	Limit
Minimum Absolute Pressure [Pa]	1
Maximum Absolute Pressure [Pa]	5e+10
Minimum Static Temperature [K]	1
Maximum Static Temperature [K]	5000
Minimum Turb. Kinetic Energy [m^2/s^2]	1e-14
Minimum Turb. Dissipation Rate [m^2/s^3]	1e-20
Maximum Turb. Viscosity Ratio	100000

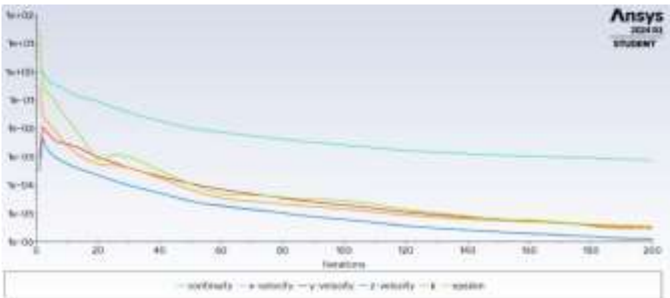

Figure 10 Graphical Representation Of Outlet Velocity

Graph Result

Iter continuity x-velocity y-velocity z-velocity k epsilon time/iter
1 1.0000e+00 3.3797e-04 9.2269e-04 3.3637e-04 2.6130e-01 2.7386e+01 0:00:00 99
2 1.0000e+00 4.7219e-03 1.1619e-02 4.7065e-03 3.3642e-02 3.3488e-01 0:01:38 98
3 6.3458e-01 2.3792e-03 8.0697e-03 2.3257e-03 1.8628e-02 1.9983e-01 0:01:37 97
4 4.9404e-01 1.6577e-03 6.5123e-03 1.6010e-03 1.4908e-02 1.6630e-01 0:01:17 96
5 4.0255e-01 1.2339e-03 4.7714e-03 1.1932e-03 1.0925e-02 1.3334e-01 0:01:01 95
6 3.5150e-01 1.0275e-03 3.7174e-03 1.0045e-03 8.4088e-03 9.2616e-02 0:01:07 94
7 3.1436e-01 8.5966e-04 3.3262e-03 8.4402e-04 5.9835e-03 6.3172e-02 0:00:53 93
8 2.7940e-01 7.3508e-04 3.1165e-03 7.2629e-04 4.4125e-03 4.2927e-02 0:00:42 92
9 2.4658e-01 6.3787e-04 2.9798e-03 6.4037e-04 3.2649e-03 3.0243e-02 0:00:51 91

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11 1.8616e-01 4.9437e-04 2.6472e-03 5.0958e-04 1.9685e-03 1.5855e-02 0:00:32 89
12 1.6229e-01 4.4219e-04 2.4387e-03 4.5519e-04 1.5708e-03 1.1570e-02 0:00:43 88
13 1.4380e-01 4.0177e-04 2.2223e-03 4.1173e-04 1.2773e-03 8.2904e-03 0:00:34 87
14 1.3041e-01 3.6705e-04 2.0003e-03 3.7624e-04 1.0845e-03 5.8466e-03 0:00:27 86
15 1.2113e-01 3.3860e-04 1.7842e-03 3.4489e-04 9.6794e-04 4.3761e-03 0:00:38 85
16 1.1449e-01 3.1147e-04 1.5583e-03 3.1611e-04 8.5570e-04 2.9921e-03 0:00:47 84
17 1.0876e-01 2.8703e-04 1.3754e-03 2.9086e-04 7.7558e-04 2.0121e-03 0:00:37 83
18 1.0308e-01 2.6442e-04 1.2177e-03 2.6816e-04 6.9670e-04 1.4371e-03 0:00:29 82
19 9.7007e-02 2.4380e-04 1.0777e-03 2.4698e-04 6.2138e-04 1.0182e-03 0:00:39 81
20 9.0091e-02 2.2479e-04 9.7300e-04 2.2580e-04 5.7245e-04 8.1170e-04 0:00:31 80
21 8.2738e-02 2.0768e-04 8.9002e-04 2.0531e-04 5.3502e-04 8.6479e-04 0:00:25 79
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33 2.9392e-02 8.2101e-05 3.2710e-04 8.1430e-05 3.3154e-04 7.4384e-04 0:00:18 67
34 2.7532e-02 7.6924e-05 3.0514e-04 7.6135e-05 3.0766e-04 6.7907e-04 0:00:27 66
35 2.5585e-02 7.2460e-05 2.8749e-04 7.1938e-05 2.8221e-04 5.9981e-04 0:00:21 65
36 2.4077e-02 6.7866e-05 2.6789e-04 6.7518e-05 2.5831e-04 5.3414e-04 0:00:17 64
37 2.2553e-02 6.3639e-05 2.5037e-04 6.3621e-05 2.3556e-04 4.7342e-04 0:00:13 63
38 2.1212e-02 5.9635e-05 2.3455e-04 5.9752e-05 2.1485e-04 4.1932e-04 0:00:23 62
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41 1.7724e-02 4.9365e-05 1.9413e-04 4.9395e-05 1.6174e-04 2.8939e-04 0:00:23 59
42 1.6646e-02 4.6288e-05 1.8245e-04 4.5998e-05 1.4689e-04 2.5699e-04 0:00:18 58
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115 1.8786e-03 4.2676e-06 1.2887e-05 4.0572e-06 9.6782e-06 1.6756e-05 0:00:35 85
116 1.7875e-03 4.1007e-06 1.2323e-05 3.9165e-06 9.4486e-06 1.5987e-05 0:00:27 84
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146 1.1668e-03 2.3985e-06 6.6553e-06 2.3697e-06 5.8562e-06 6.6190e-06 0:00:18 54
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160 1.0648e-03 1.9038e-06 5.3850e-06 1.9776e-06 5.0852e-06 5.8056e-06 0:00:13 40
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199 8.0520e-04 1.2216e-06 3.1653e-06 1.2916e-06 3.4763e-06 2.9066e-06 0:00:00 1
200 7.4200e-04 1.2005e-06 2.9398e-06 1.2883e-06 3.4384e-06 2.8651e-06 0:00:00 0

VII. CALCULATIONS

Nomenclature & Values
ri = inner radius [mm or in] = 7.5 mm
ro = outer radius [mm or in] = 3 mm
pi = internal pressure [N/m^2 or psi] = 32.2 N/m^2
po or pt = external or stagnation pressure [N/m^2 or psi] = 15 N/m^2
r = radial variable [mm or in] = 10 mm

d = exit nozzle diameter [mm] = 6 mm

l = length of nozzle [mm] = 50 mm

t = thickness at nozzle exit [mm] = 2mm

π = 3.14

γ = the ratio of specific heats (4.186 for water)

M = the Mach number at the exit = 0.1

ρe = the density of the fluid at the nozzle exit

Ve = the velocity of the fluid at the nozzle exit

R = the specific gas constant = 287.26 J/KgK

Te = the static temperature at the nozzle exit

T_t = total temperature = 288 K

Hoop Stress
At Nozzle Exit
Bursting Force (FB) = $\pi \times d \times L$ = 942 N
Resisting Force (FR) = $2t \times L$ = 200 N
Hoop stress acting on the wall thickness (h) = $\pi d/(2t)$ = 4.71 Pa.
For thick-walled nozzle, hoop stress is given by:
$\sigma h = ri^2pi - ro^2po - ri^2ro^2(po-pi)/r^2 / ri^2 - ro^2 = 905.30$ **Pa**

Static Pressure at Nozzle Exit

$$Pe = Pt\ (1+ \gamma-1/2\ M^2)^{-\gamma-1/\gamma} = 14.69\ N/m^2$$

Dynamic Pressure at Nozzle Exit
Static temperature
$Te = Tt\ (1+ \gamma-1/2\ M^2)^{-1} = 283.48$ **K**

Exit velocity
$V_e = M\sqrt{\gamma R T_e} = 58.38$ m/s

Density at nozzle exit
$\rho_e = P_e/RT_e = 1.8034 \times 10^{-4}$ Kg/m^3

Dynamic Pressure
$q = ½ \rho_e V_e^2 = 0.307$ N/m^2

Therefore, the hoop stress is 905.30 Pa & The static and dynamic pressure at nozzle exit is 14.69 and 0.307 N/m^2.

VIII. CONCLUSION

This paper has proposed a nozzle design for waterjet propulsion system in unmanned aerial vehicle. The purpose of this nozzle is to enhance the utilization of autonomous water-jet propulsion devices by improvising flow velocity which is going for specialized applications, particularly in rescue and aquatic ecosystem surveillance.

The thrust force generated by the water jet propulsion system was highly dependent on the amount of flow capacity generated by the pump used. The larger the capacity produced by the pump with a constant nozzle diameter, the nozzle flow rate will also be greater so that the resulting thrust would also be greater.

The waterjet propulsion system is conceptual design for unmanned water powered aerial vehicle but, after the analysis of the nozzle it seems increased in velocity and decreased in pressure at nozzle exit, nozzle can produce required thrust which can lift-up the unmanned aerial vehicle.

Thus, the conical nozzle is better option for waterjet propulsion system instead of bell type nozzle.

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