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# Influence of Ducted Propeller on Ro-Ro Vessels for Indonesia Inter-island Transportation

Achdri Fauzi Nugraha Oloan[1*], Prabuditya Bhisma Wisnu Wardhana [2], Agung Fauzi Hanafi[3],Yeddid Yonatan Eka Darma [4]

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***Abstract*— These Ro-Ro vessels are the backbone of inter–island transportation in Indonesia and require an efficient propulsion system to reduce fuel consumption and improve maneuvering performance. This study investigates the influence of ducted propellers on Ro-Ro vessels using Computational Fluid Dynamics (CFD) simulations. Four blades fixed pitch propeller configuration with accelerating duct are examined with different radial gaps at the propeller tip to the inner duct surface (0.1m, 0.3m and 0.5m) at rotational speed of 229 rpm and diameter of 4.202 m. the CFD model validation show average deviation of 4.06 % for KT, 7.63 % for 10*KQ and 3.11 % for efficiency compared with the experimental data. It indicated that the numerical approach is sufficiently reliable for further analysis. The open-water test results suggest that adding a duct does not necessarily improve performance. At a 0.10m gap, thrust, torque, and efficiency decrease by 39.3%, 25.7%, and 20.3%, respectively, whereas the 0.5m gap still results in noticeable performance degradation. Wake-field visualization indicates that smaller gaps produce stronger propeller–duct interaction, with more concentrated energy, sharper velocity gradients, and greater instability near the duct outlet. These findings emphasize that duct geometry and tip clearance must be carefully optimized for the vessel's operating conditions to fully realize the energy benefits of a ducted propeller system on Ro-Ro vessels.**

*Keywords*— Thrust, Torque, Efficiency, Ducted, CFD, Ro-Ro

[*]*Corresponding Author: fauzioji@gmail.com*

## I. INTRODUCTION

The Ro-Ro Vessels (Roll on – Roll off) are the backbone of the Indonesian economy. Those who carry vehicles like cars and trucks for inter-island travel in Indonesia often face challenges at sea. They need strong thrust from propellers for quick maneuvers in busy ports and for fuel savings on long trips, but regular propellers can sometimes be inefficient. This is where ducted propellers come in as a simple solution. Inter–island sea transportation in Indonesia relies heavily on Ro-Ro ferries, which carry a large number of passengers and vehicles between islands. These ships must operate on tight schedules with efficient fuel consumption so they can provide affordable services for the wider community [2].

In practice, many Ro-Ro vessels still experience high fuel consumption and actual speed that do not match their design values. At present, studies show that the primary cause is a propulsion system that is not yet fully optimized, especially in terms of propeller selection and design that do not match the ship's operating conditions [9]. High rotation can produce air bubbles around blades, which can impact propeller efficiency [12]. The ship's propeller is the primary component responsible for converting engine power into thrust, propelling the vessel forward. If the propeller selection is not suitable for the engine characteristics and operating profile, the engine will work at non-optimal load and efficiency levels, resulting in significant fuel waste [10]. Along with rising fuel prices and stricter international regulations on emission reduction, the Indonesian maritime sector needs technical solutions to improve ship energy efficiency [16]. To increase propulsion efficiency, impact on the design propellers gives a 2-4% improvement and adding a propeller duct or nozzle gives 5 % of fuel saving at cruise speed [8]. A Kort nozzle or duct made from plateshaped foil has a principal working concentrated water flow to the propeller which can maximize energy absorption by propeller [11]. A nozzle design has two types: the accelerating nozzle and the decelerating nozzle. Accelerating the type can increase propeller efficiency and decelerating can reduce vibration and noise [6]. Higher pressure coefficient at the suction and pressure side can generate higher thrust and torque [7]. Installing a ducted propeller or a Kort nozzle, a propeller surrounded by a specially shaped duct. Adding a kort nozzle to a propeller can significantly increase thrust, especially for heavily loaded vessels such as tugs and workboats [1]. Kort nozzle length has a relationship with thrust, causing greater length to produce a smaller thrust, and for torque, it is also the same result [13].

A Kort nozzle with MARIN type can give results for the increase and decrease in thrust and torque under certain conditions [15]. In some cases, the addition of a kort nozzle can decrease propeller thrust, torque, and

Achdri Fauzi Nugraha Oloan is with Study Program of Ship Manufacturing Engineering, Politeknik Negeri Banyuwangi, Banyuwangi, 68461, Indonesia, E-mail : achdri@poliwangi.ac.id

Prabuditya Bhisma Wisnu Wardhana is with Study Program Automotive Engineering, Politeknik Negeri Banyuwangi, Banyuwangi, 68461, Indonesia, E-mail: prabuditya@poliwangi.ac.id

Agung Fauzi Hanafi is with Study Program Automotive Engineering, Politeknik Negeri Banyuwangi, Banyuwangi, 68461, Indonesia, E-mail: agung@poliwangi.ac.id

Yeddid Yonatan Eka Darma is with Study Program of Ship Manufacturing Engineering, Politeknik Negeri Banyuwangi, Banyuwangi, 68461, Indonesia, E-mail: yeddidyonatan@poliwangi.ac.id

efficiency, as analyzed in computational fluid dynamics open-water tests [3]. Instability phenomena can be found at the tip leakage vortex in the wake and it can create turbulence conditions [18]. Tip vortex interaction from the propeller/nozzle can cause strong vortices in the entire domain ( without the nozzle ). With the nozzle, it can reduce the tip vortex at the blade due to the interaction effect of the nozzle's viscous wake [17]. This research is designed to fill the gap by analyzing the specific influence of Duct Propellers on Ro-Ro Vessels Used for Inter-Island Transportation in Indonesia. By combining CFD simulation, it can deliver information for the subsequent development and recommendations.

TABLE 1.
MAIN DESIGN PROPELLER AND DUCTED

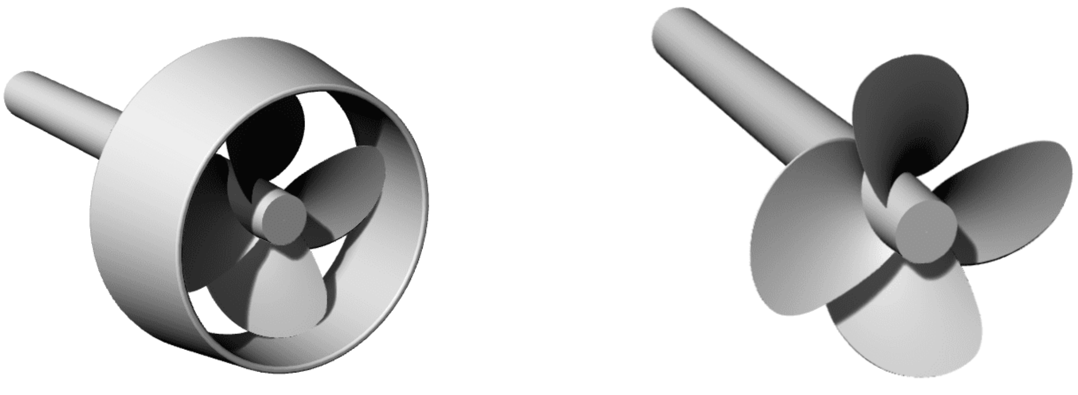
| Propeller | A | B | C |
|---|---|---|---|
| Blade | 4 | 4 | 4 |
| Diameter (m) | 4.202 | 4.202 | 4.202 |
| Speed (Rpm) | 229 | 229 | 229 |
| Duct Type | Accelerating | Accelerating | Accelerating |
| Duct Gaps (m) | 0.10 | 0.30 | 0.50 |

## II. METHOD

### A. Model Test Cases

As shown in Table 1, the propeller is used to assess the impact of duct use. Three model test forms differ in the interaction between the gap (0.10m, 0.30m, and 0.50 m) at the propeller tip and the area inside the duct, using the accelerating type. The current analysis also considers the geometry of three four-blade propellers with fixed pitch installed with the accelerating duct. In all three cases, the propulsion system is designed for its specific operating conditions to maximize energy efficiency and minimize cavitation risk. It can reduce torque at low speeds and operate at a maximum of 299 rpm.

Geometry design and drawing using CAD application. Making 3d solids from wireframes into parasolid forms without gaps and closed surfaces so that they can be used to produce meshing or cells and can be analyzed using CFD analysis. A total of four models, each with three duct configurations, were used in this study. From Figure 1, the difference between using and not using a duct for the propeller is shown. Ensure that gaps between the propeller's tips do not merge with the inner surface duct, which can be an error in the solid definition model used in the CFD software.



(a) With Duct (b) Without Duct

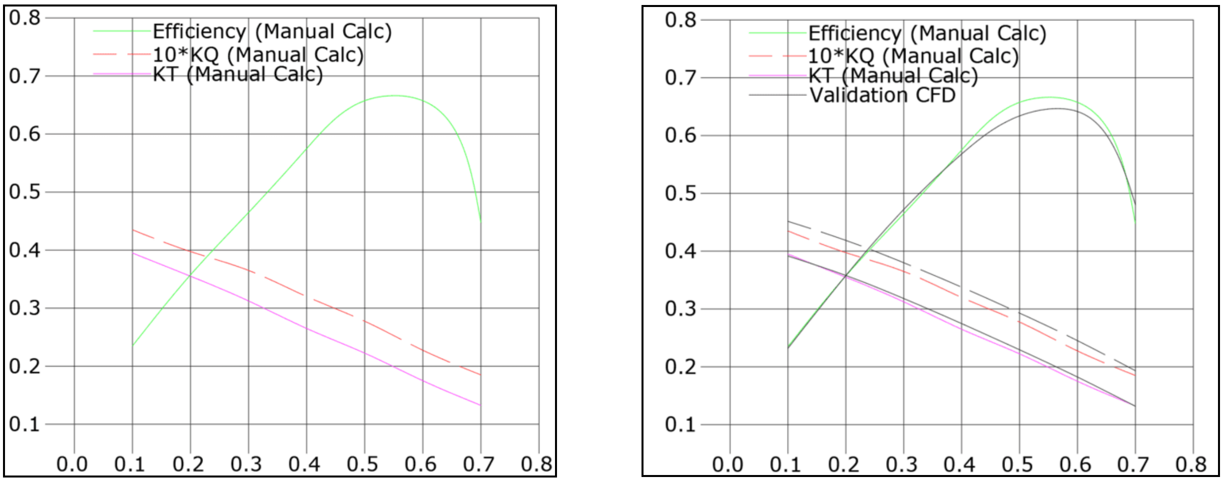
**Figure 1.** Isometric view of propeller with and without duct

### B. Validation Result

Validation taken by open-water characteristic. Model validation is a propeller without a duct, comparing numerical calculations with CFD results. The result can be plotted at the propeller's thrust (KT), the propeller's torque (KQ), and the propeller's efficiency (ηo). Thrust values are taken by the force value on the propeller's rotation until the fluid can propel the ship, and the torque values can be taken by the x-axis with the direction of fluid movement [5] Location for data simulation, from J = 0.10 to J = 0.70, and environmental conditions such as Va and water density. Equation (1) can be used to calculate the numerical method and process the raw results from CFD software. Percentages of error can be found by equation (2), where the relative error between two parameters [14].

$$J = \frac{V_A}{n_D}, K_T = \frac{T}{\rho n^2 D^4}, K_Q = \frac{Q}{\rho n^2 D^5}, \eta_O = \frac{J}{2\pi} + \frac{K_T}{K_Q} \quad (1)$$

$$e_{21} = \left|\frac{f_2 - f_1}{f_1}\right| \quad (2)$$




(a) With Duct (b) Without Duct

**Figure 2**. Difference plot graph from validation

TABLE 2.
VALIDATION KT, 10*KQ & ETA

| Advanced Ratio (J) | KT EFD | KT CFD | KT % | 10*KQ EFD | 10*KQ CFD | 10*KQ % | ETA EFD | ETA CFD | ETA % |
|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 0.295 | 0.292 | 1.13 | 0.335 | 0.352 | 4.71 | 0.135 | 0.132 | 2.19 |
| 0.20 | 0.255 | 0.258 | 1.19 | 0.298 | 0.319 | 6.66 | 0.258 | 0.258 | 0.13 |
| 0.30 | 0.213 | 0.218 | 2.68 | 0.265 | 0.280 | 5.37 | 0.365 | 0.372 | 1.93 |
| 0.40 | 0.165 | 0.175 | 5.92 | 0.220 | 0.238 | 7.49 | 0.475 | 0.468 | 1.47 |
| 0.50 | 0.123 | 0.129 | 5.68 | 0.178 | 0.193 | 8.05 | 0.558 | 0.534 | 4.41 |
| 0.60 | 0.075 | 0.082 | 9.81 | 0.085 | 0.145 | 12.25 | 0.558 | 0.542 | 2.95 |
| 0.70 | 0.033 | 0.032 | 2.03 | 0.033 | 0.093 | 8.86 | 0.348 | 0.381 | 8.69 |
| Average | | | 4.06 | | | 7.63 | | | 3.11 |

Data from Table 2: validation between EFD vs CFD models. Average deviation from the advanced ratio from 0.10 to 0.70: KT is 4.06%, with a higher value at J=0.60 (9.81%) and a lower value at J=0.10 (1.13%). Average deviation from the advanced ratio from 0.10 to 0.70: 10*KQ is 7.63%, which is higher at J=0.60 (12.25%) and lower at J=0.10 (4.71%), average deviation from the advanced ratio from 0.10 to 0.70. ETA is 3.11%, with a larger value at J=0.60 (2.95%) and a lower value at J=0.20 (0.13%). All CFD results can be used to continue analysing the phenomenon of propeller-gap variations in the duct and to assess the effects following installation.

## III. RESULTS AND DISCUSSION

### A. Openwater Test (CFD)

Geometry design and drawing using CAD application. Making 3d solids from wireframes into Parasolid forms without gaps and closed surfaces so that they can be used to produce meshing or cells and can be analysed using CFD analysis. Figure 3 shows a four–blade ducted propeller configuration with a left-hand rotation at 229 rpm. Complete with a flow inlet point (A) and an outlet point (B) in the duct channel. Hydrodynamically. The duct guides the inlet flow toward the propeller flow, thereby making the velocity with distribution near the blade and hub more uniform and reducing energy losses at the blade tip. This scheme also emphasises the geometric relationship between the shaft, hub and duct as an integrated propulsion system designed to maximise thrust at low speeds while increasing the overall propulsion efficiency of the ships. CFD can provide information to understand engineering to identify the performance of the propeller and the fluid vortex [4].

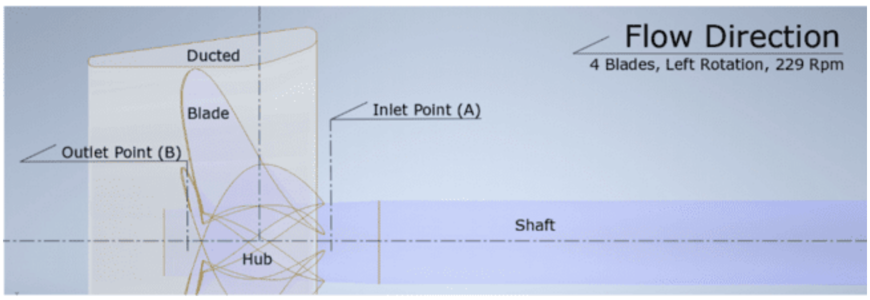



**Figure 3.** Cross-section openwater test propeller with ducted

TABLE 3.
PROPELLER VS PROPELLER WITH DUCT KT (0.5M GAPS)

| Advanced Ratio (J) | KT CFD | KT DUCT | KT % | 10*KQ CFD | 10*KQ DUCT | 10*KQ % | ETA CFD | ETA DUCT | ETA % |
|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 0.292 | 0.254 | -12.8 | 0.352 | 0.314 | -10.6 | 0.132 | 0.129 | -2.48 |
| 0.20 | 0.258 | 0.229 | -11.2 | 0.319 | 0.291 | -8.7 | 0.258 | 0.251 | -2.80 |
| 0.30 | 0.218 | 0.192 | -11.8 | 0.280 | 0.256 | -8.7 | 0.372 | 0.359 | -3.45 |
| 0.40 | 0.175 | 0.151 | -13.6 | 0.238 | 0.215 | -9.5 | 0.468 | 0.477 | -4.48 |
| 0.50 | 0.129 | 0.107 | -17.6 | 0.193 | 0.171 | -11.4 | 0.534 | 0.497 | -6.94 |
| 0.60 | 0.082 | 0.006 | -26.5 | 0.145 | 0.124 | -15.0 | 0.542 | 0.468 | -13.6 |
| 0.70 | 0.032 | 0.011 | -65.8 | 0.093 | 0.072 | -23.0 | 0.381 | 0.169 | -55.6 |
| Average | | | -22.8 | | | -12.4 | | | -12.7 |

The results of the analysis with and without a duct, at 0.5m gaps between the propeller tip and the internal duct surface, are shown in Table 3. This duct configuration experiences a significant reduction, with an average decrease of approximately 22.8% in thrust and approximately 12.4% in torque relative to the configuration without it. This decrease is directly reflected in the propulsion efficiency, which decreases by an average of 12.7% even at J=0.7, with a degradation exceeding 50%. It can be concluded that gaps of 0.5m result in underperformance, as the flow within the duct no longer acts as an accelerator but instead creates additional hydrodynamic losses and reduces the tip clearance benefits that would otherwise be obtained from a ducted propeller system.

TABLE 4.
PROPELLER VS PROPELLER WITH DUCT KT (0.3M GAPS)

| Advanced Ratio (J) | KT CFD | KT DUCT | KT % | 10*KQ CFD | 10*KQ DUCT | 10*KQ % | ETA CFD | ETA DUCT | ETA % |
|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 0.292 | 0.248 | -14.8 | 0.352 | 0.310 | -11.7 | 0.132 | 0.127 | -3.61 |
| 0.20 | 0.258 | 0.226 | -12.3 | 0.319 | 0.290 | -9.06 | 0.258 | 0.249 | -3.56 |
| 0.30 | 0.218 | 0.188 | -13.8 | 0.280 | 0.253 | -9.78 | 0.372 | 0.356 | -4.48 |
| 0.40 | 0.175 | 0.146 | -16.4 | 0.238 | 0.211 | -11.2 | 0.468 | 0.440 | -5.91 |
| 0.50 | 0.129 | 0.102 | -21.0 | 0.193 | 0.167 | -13.6 | 0.534 | 0.488 | -8.63 |
| 0.60 | 0.082 | 0.057 | -30.7 | 0.145 | 0.120 | -17.3 | 0.542 | 0.453 | -16.29 |
| 0.70 | 0.032 | 0.008 | -74.9 | 0.093 | 0.069 | -25.6 | 0.381 | 0.128 | -66.30 |
| Average | | | -26.3 | | | -14.0 | | | -15.5 |

Table 4 shows the comparison between a bare propeller and a duct configuration in which the radial gaps between the propeller tip and the inner surface of the duct are 0.3m. All advanced ratios J, the ducted arrangement produces a lower thrust coefficient KT, torque coefficient 10*KQ, and propulsive efficiency $\eta$ than without a duct. With average degradation of about 26.3 % in thrust, 14 % in torque and 15.5 % in efficiency. This pattern suggests that a 0.3m gap clearance can disturb the inflow, increasing viscous and separation losses.

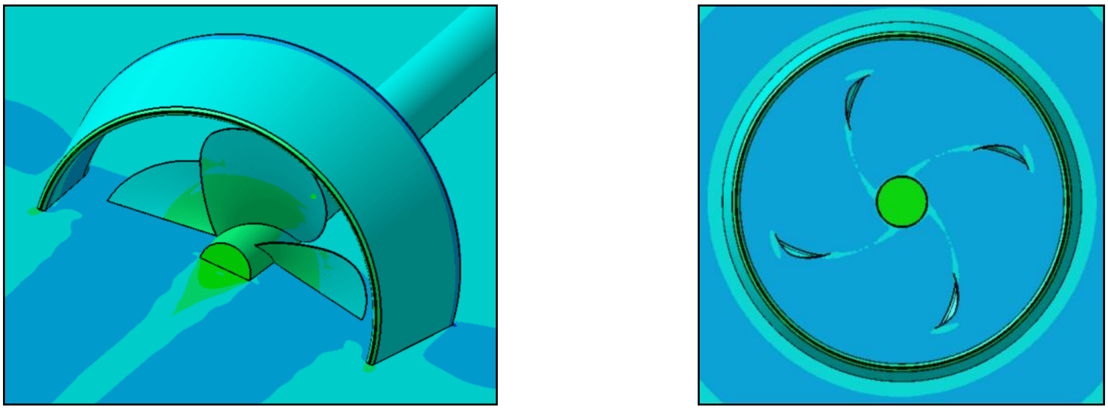
TABLE 5.
PROPELLER VS PROPELLER WITH DUCT KT (0.1M GAPS)

| Advanced Ratio (J) | KT CFD | KT DUCT | KT % | 10*KQ CFD | 10*KQ DUCT | 10*KQ % | ETA CFD | ETA DUCT | ETA % |
|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 0.292 | 0.105 | -63.9 | 0.352 | 0.175 | -50.2 | 0.132 | 0.096 | -27.58 |
| 0.20 | 0.258 | 0.201 | -21.9 | 0.319 | 0.270 | -13.3 | 0.258 | 0.238 | -7.81 |
| 0.30 | 0.218 | 0.180 | -17.4 | 0.280 | 0.249 | -11.0 | 0.372 | 0.345 | -7.21 |
| 0.40 | 0.175 | 0.133 | -23.7 | 0.238 | 0.201 | -15.2 | 0.468 | 0.421 | -10.05 |
| 0.50 | 0.129 | 0.091 | -29.7 | 0.193 | 0.157 | -18.4 | 0.534 | 0.460 | -13.85 |
| 0.60 | 0.082 | 0.043 | -47.2 | 0.145 | 0.108 | -25.9 | 0.542 | 0.386 | -28.70 |
| 0.70 | 0.032 | 0.009 | -70.3 | 0.093 | 0.052 | -43.9 | 0.381 | 0.201 | -47.07 |
| Average | | | -39.2 | | | -25.7 | | | -20.3 |

Table 5 shows the detailed comparison between without duct ( CFD based ) and the ducted propeller for a configuration in which the radial gap between the propeller tip and the inner surface of the duct is 0.1m.the data clearly show that every advance ratio J, the ducted configuration produces substantially lower thrust coefficient KT, torque coefficient 10*KQ, and propulsive coefficient $\eta$ than without a duct with average reductions about 39.2% in thrust, 25.7% in torque and 20.3% in efficiency. When these CFD-predicted trends are contrasted with typical EFD (experimental) results for designed ducted propellers, which typically indicate a thrust gain at low to moderate J. The present CFD solution demonstrates that the selected 0.1m gap tip clearance and duct geometry drive the system far from its optimal operating range, rather than functioning as an accelerating nozzle, as observed in EFD studies. The duct in this configuration appears to introduce substantial additional viscous and separated losses.

*B. Wake Fields*

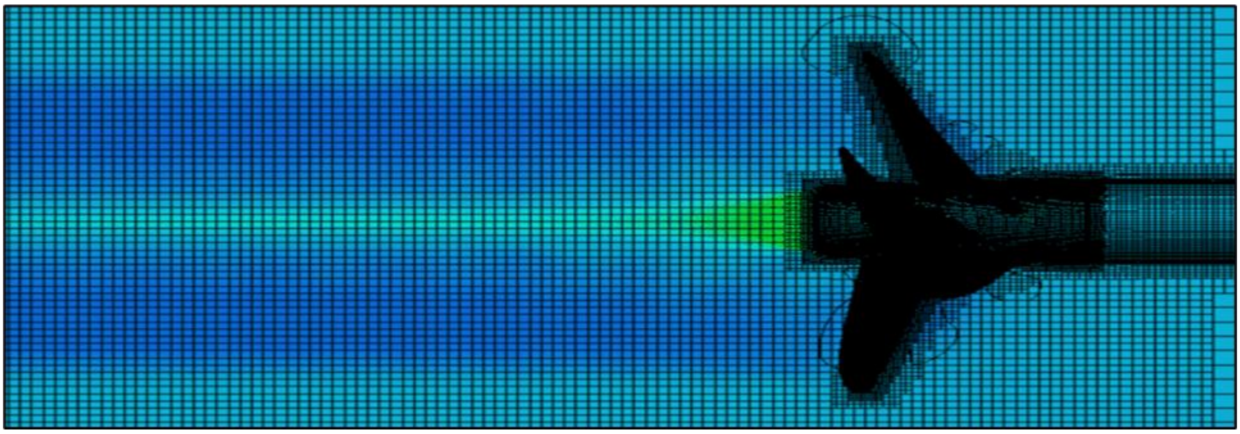
Wake field behind a propeller with a duct is characterized by a strong interaction between the rotor and the nozzle that reshapes velocity and vortex structures in the downstream flow. In general, the nozzle accelerates and redirects the inflow so that the axial velocity through the propeller becomes more uniform, reducing the intensity of tip vortices and wake contraction compared with a conventional open propeller under similar loading. At low advantage coefficients, studies show that this interaction can stabilize the wake, recover part of the energy that would otherwise be lost in the wake, and thereby improve propulsive efficiency. In contrast, at higher loading or with non-optimal clearances, the duct may generate additional secondary vortices and instabilities that complicate the wake pattern and can offset some of the expected performance gains.



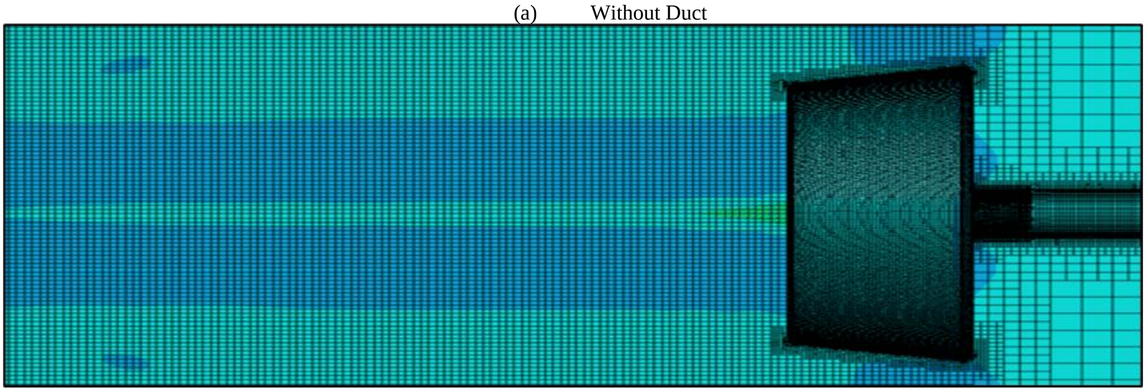
(a) Velocity at X value (b) Velocity at Y value

**Figure 4**. Velocity at Ducted Propeller (0.5m) Gaps

Figure 4 show the velocity pattern around a ducted propeller with a 0.5m gap between the propeller tip and the inner wall of the duct, viewed in two different flow, the X plane (a) and the Y plane slice, the bladewake appears as four blades tip rotating traces, and the 0.5m clearance causesthe flow near the duct wall to be insufficiently accelerated. So a considerable amount of energy is lost in the region between the propeller tips and the duct, which has resulted in potential decreases in efficiency.



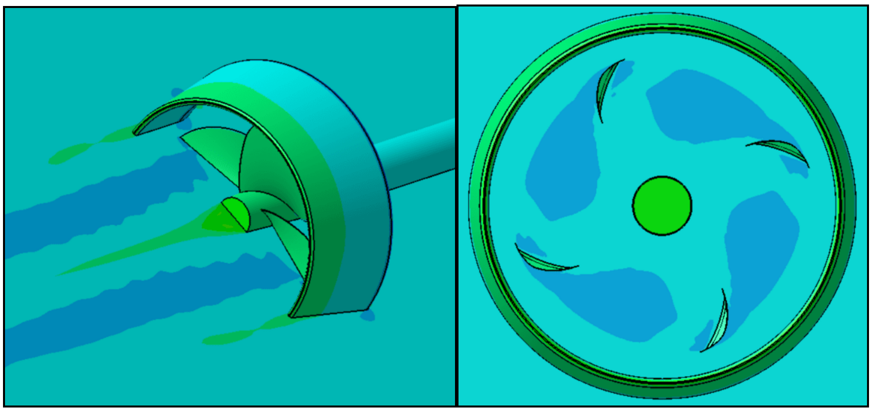
(a) Without Duct



(b) With Duct

**Figure 5.** Velocity at Ducted Propeller (0.5m) Gaps

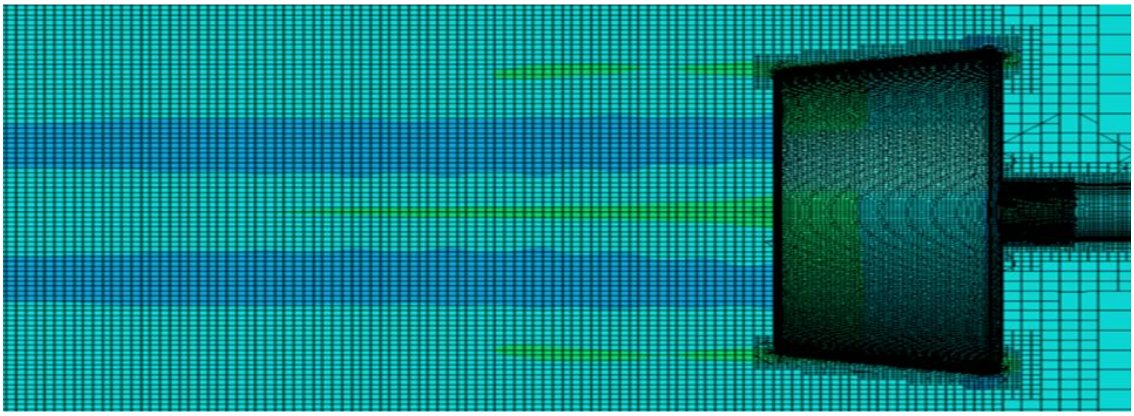
Figure 5 illustrates the difference in wake field characteristics between a propeller with and without a duct. In the configuration without a duct (a), the high velocity jet behind the propeller extends downstream as a narrow core along the flow axis, with a sharp velocity gradient between the plane and the surrounding flow. Then the energy leaving the propeller tends to be concentrated and can easily form strong vortices further downstream in contrast to the configuration with a duct (b). The wake pattern appears more truncated and more evenly distributed within the duct cross section, the high velocity region at the wake center becomes more controlled, and the lateral velocity gradient is reduced, indicating that the duct acts as a flow conditioner that damps the spread of free vortices while stabilizing the wake before it enters the far wake region behind the propeller.



(a) Velocity at X value (b) Velocity at Y value

**Figure 6.** Velocity at Ducted Propeller (0.3m) Gaps

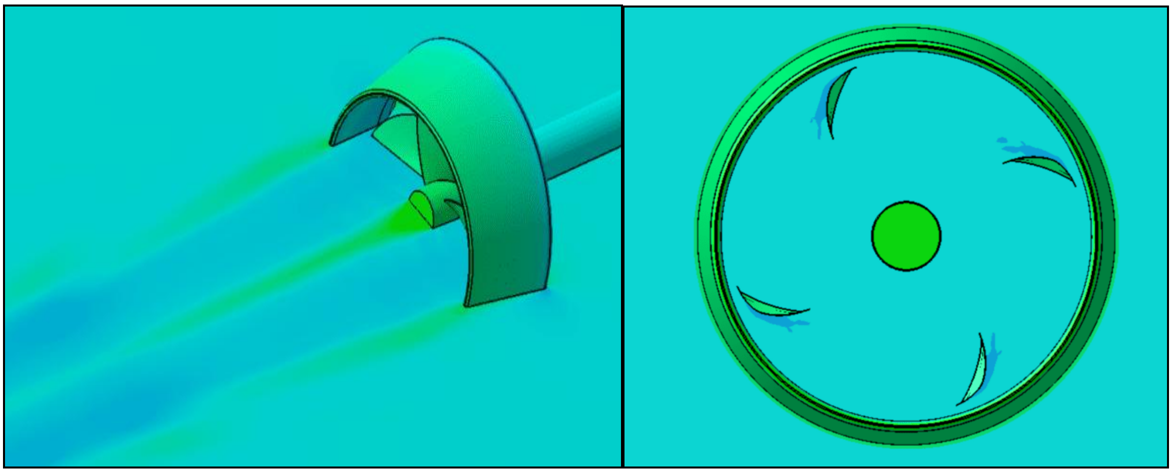
Result for this figure 6, compared with Figure 4. At 0.3m gap, both the X nd Y plane views show a more fragmented wake with narrow high velocity streaks and a large medium velocity region inside the duct, indicating a stronger but less uniform propeller–duct interaction that produces sharp velocity gradients near the duct wall and a less homogeneous slipstream. At o.5m gap, the wake pattern becomes smoother and more diffuse, the blade traces remain visible, but the transition from the wake core to the surrounding flow is more gradual.



(a) With Duct

**Figure 7.** Velocity at Ducted Propeller (0.3m) Gaps

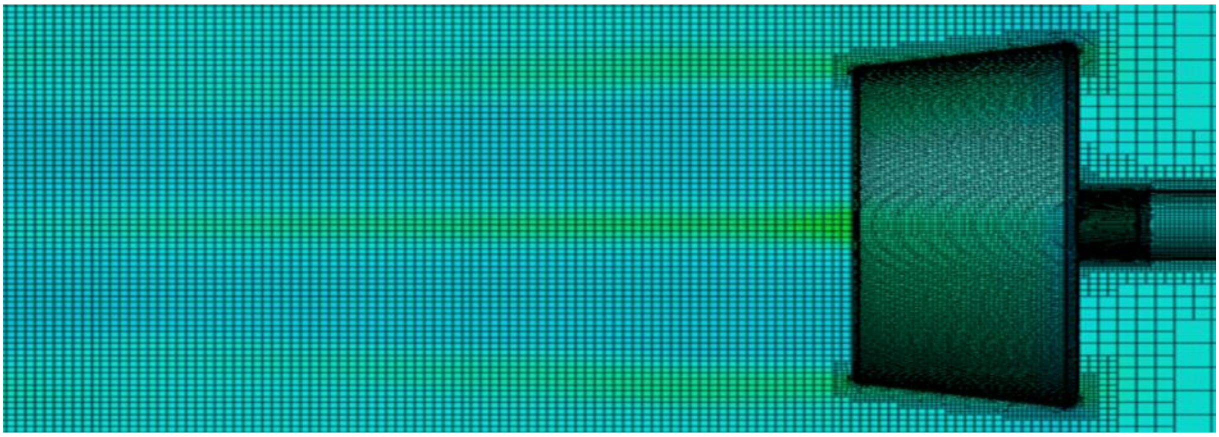
If comparing the results between figure 6 and figure 7, a smaller 0.3m clearance has an impact on the velocity jet emerging from the duct, which appears more concentrated and exhibits a sharper contrast between high-speed core and the surrounding flow, indicating a stronger acceleration effect but also steeper velocity gradients that may promote higher losses and instability in the near wake. At larger 0.5m gaps, the jet leaving the duct is visibly more diffuse, and the velocity bands are smoother and more uniform across the cross-section, which suggests that the duct conditions stabilize the flow with weaker acceleration, leading to a more gentle wake but less focused discharge of kinetic energy behind the propeller.



(a) Velocity at X value (b) Velocity at Y value

**Figure 8.** Velocity at Ducted Propeller (0.1m) Gaps

Result of 0.1m gap ( Figure 8 ), compared with 0.5m gaps and 0.3m gaps configuration. The wake field at 0.1m gap appears focused and streamlined, with the x-axis slice showing a relatively narrow, strongly axial velocity jet. In contrast, at 0.3m the plane begins to split into several streaks with sharp gradients near the duct wall and at 0.5m, the wake pattern becomes more diffuse so that the flow energy is no longer concentrated in the wake core. In the Y-axis slice, a 0.1m gap displays sharp blade traces very close to the duct wall, indicating strong tip – duct interaction and potential thrust contribution from the duct. In contrast, at 0.3m traces move farther away and are surrounded by a wide medium velocity region and at 0.5m they become thinner with a more homogeneous but less accelerated velocity distribution. In other words, reducing the gap from 0.5m to 0.1m shifts the wake from every spread and stable pattern (o.5m) to a more focused but not uniform pattern (0.3m) and finally to the most concentrated wake with the strongest propeller–duct interaction at 0.1m.



(a) With Duct

**Figure 9**. Velocity at Ducted Propeller (0.1m) Gaps

In comparison with the 0.5m and 0.3m gap variations, the wake field in this image with a smaller tip-duct clearance appears more concentrated and better confined by the duct. At a 0.5m gap, the CFD results show a broader, more diffuse jet where the high velocity core spreads out relatively quickly downstream and the velocity layers across the wake are smoother but less accelerated, indicating that the duct acts more as a gentle flow conditioner than a strong nozzle. At a 0.30m gap, the jet becomes narrower and more energetic than at 0.5m, yet still exhibits noticeable lateral spreading and segmented streaks, so the acceleration effect is stronger, but the wake remains partially non-uniform. In the present case, with a smaller clearance, the high-speed core is elongated and tightly aligned with the shaft axis. Suggesting the strongest confinement and directional control of the wake among the three gaps, at the expense of stepper velocity gradients at the duct exit and a higher risk of viscous and unsteady losses in the near wake region.

## IV. CONCLUSION

From that research, a comparative analysis of the propeller with and without a duct can be concluded :

1. Openwater test analysis has the result of validation with bare propeller (without duct) showing good gaps between numerical calculation EFD vs CFD for the curves of KT, 10*KQ and efficiency. The CFD model can be considered reliable for studying the effect of adding a duct. When the duct is installed with tree tip – duct gaps clearance 0.10m, 0.30m, and 0.50m, the opwnwater results indicate

that the duct does not automatically improve performance. In several configurations, thrust, torque and efficiency actually decrease because of the interaction between the wake flow inside the duct. This confirms that the duct geometry and tip clearance must be carefully optimized for the ship's operating conditions since an inappropriate configuration can reduce the potential energy benefits of a ducted propeller.

2. The CFD velocity contour shows that the variation of the gaps strongly affects the wake structure behind the ducted propeller. At the largest gap (0.5m), the wake appears smoother and more diffused with a high velocity jet that spreads relatively quickly, so that the energy is not concentrated in the wake core. At the intermediate gap (0.3m), the jet becomes narrower and more energetic. Still, the wake inside the duct is fragmented and exhibits a sharp velocity gradient near the duct wall, which may increase losses and instabilities. At the smallest gaps (0.1m), the wake is more focused. The X-axis slice shows a narrow, strongly axial jet. In contrast, the Y-axis slice reveals sharp blade traces close to the duct wall, indicating very strong tip – duct interaction and maximum flow confinement, but also higher velocity gradient and instability in the near outlet region of the duct.

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